iMOVE 6-002
Australian Size Variation for Design

M004: Detailed anthropometry dataset

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Executive Summary

This is the final report for iMOVE project z-002 “Australian Size Variation for Design”.

The overarching goal of the project was to provide a reference anthropometry dataset for the Australian adult population. The primary intended use was for Human Factors and design considerations within the Australian transport industry. To our knowledge, this is the first time detailed anthropometric data has been released for Australian adults, and as such, the uses of such a dataset can potentially reach outside of this field.

Anthropometric data (height and weight) were obtained from 2014 and 2017 cohorts of the Australian National Health Survey (NHS). A statistical method previously used for the US population was used to estimate other anthropometric dimensions from the NHS data, using the Civilian American and European Surface Anthropometry Resource (CAESAR) as the detailed dataset.

In the report, we present the main percentiles relevant to Human Factors, for a selection of 43 anthropometric measures. Data are provided for 18-64 years old Australian adults, males and females separately. The full anthropometric dataset, which comprises 105 individual measures, is provided in Appendix 2.

In addition, we describe the methods used to obtain, sample and reweigh the NHS data, and present some quality checks for the reweighting process. We also compare this dataset to the most commonly used reference for Australian anthropometry, the PeopleSize software. We also provide some general guidance for the use of anthropometry in the context of Human Factors and design assessment.

Finally, we present a review of the literature for three factors related to anthropometry, and of potential importance in Human Factors: secular trends in anthropometry, i.e. the evolution of a population’s body size over long time scales; the relation between ethnicity and anthropometry; and the influence of clothing and personal equipment on space requirements.

Detailed Australian Adult Anthropometry

Introduction

This section presents the detailed anthropometric dimensions for Australian male and female adults, aged 18-64.

1. The source data were obtained from the National Health Surveys (NHS, combined 2014 and 2017 time points), where height and weight data were collected on a representative sample of approximately 20,000 Australian adults (age 18-64).

2. From these data, a statistical distribution was fitted (“skew normal bivariate distribution”), then synthetic individual datasets were generated from the distribution.

3. An anthropometry reweighting method was then applied, using the above synthetic data as the reference dataset, and CAESAR US as the detailed dataset.

4. This process resulted in a detailed dataset of Australian adult anthropometry, comprising 105 anthropometric measurements, which was the primary objective of the present project.

Figure 1 on the following page presents an overview of these steps.

Step 1 (NHS data extraction and basic anthropometry) has been presented in detail in a previous project report (Milestone 2 report).

Step 2 was needed because ABS data access restrictions prevented us from using the actual individual NHS data in the reweighting process. This section presents the development and evaluation of the distribution fitting, and generation of synthetic data from the distribution.

The development and evaluation of the reweighting method of Step 3 were performed earlier in the project, and are presented in Appendix 1. Therefore, we only provide here a summary of the process.

Finally, we present the detailed Australian adults anthropometry data, including a selected set of 43 dimensions from the full set of 105, and provide comparisons with the source NHS data and with the data from PeopleSize software, which is the most commonly use source of anthropometry data for designers in the transport industry.

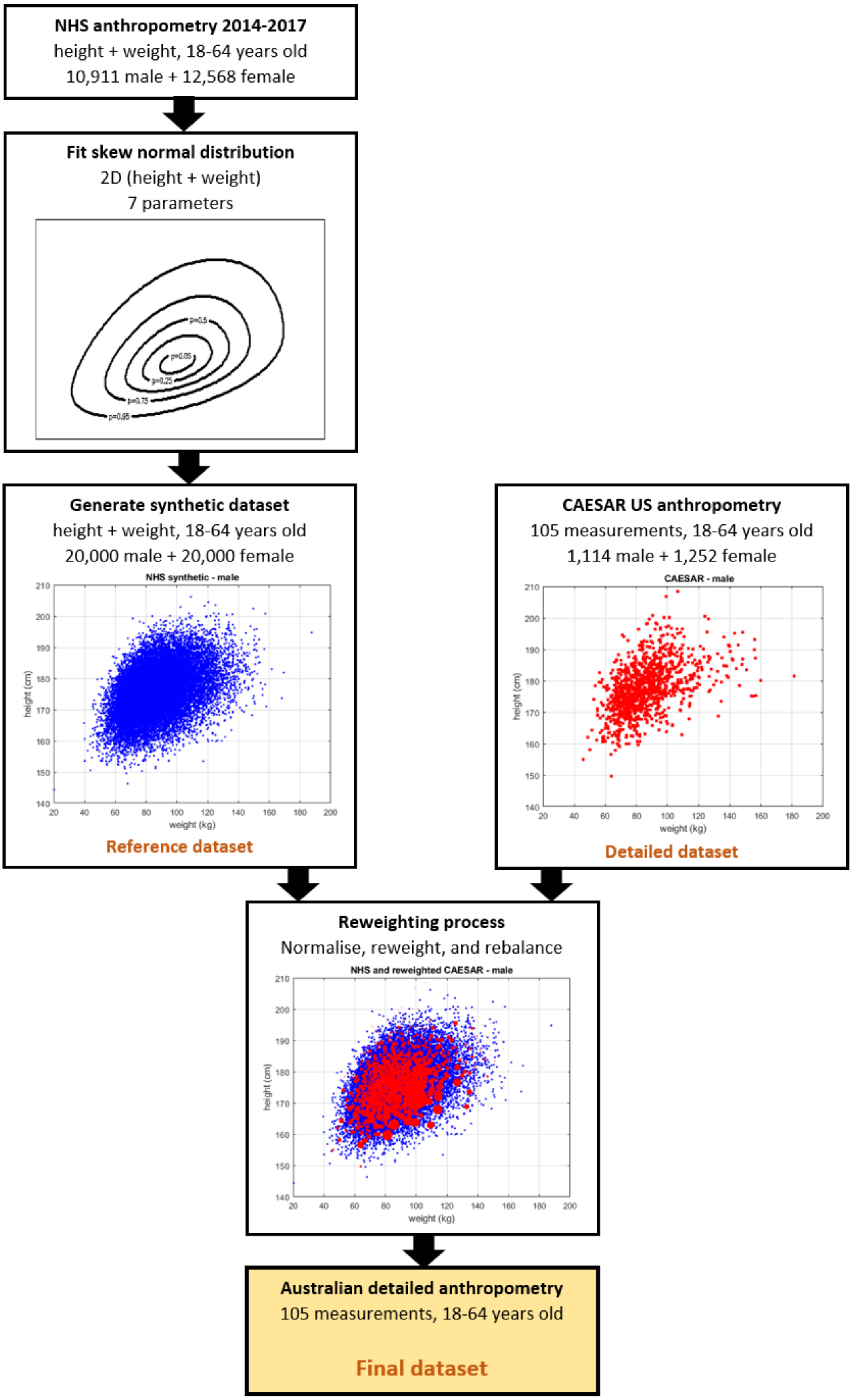

Figure 1 - overview of the process used to obtain the detailed Australian adults' anthropometry dataset.

Context

In the first part of this project, we obtained access to the National Health Surveys (NHS) anthropometric data, through the ABS's Datalab online repository.

The NHS database contains objectively measured height and weight data for a sample of approximately 20,000 Australians (age 2 years and over, approx. 10,000 female), and is available for the 2008, 2011, 2014 and 2017 timepoints. Because of differences in measurement protocol, we elected to use the 2014 and 2017 timepoints only. Refer to Milestone 2 report for details on the NHS anthropometry data and associated methods.

The main goal of the project was to obtain *detailed* anthropometric data for the Australian population, meaning a set of (estimated) anthropometric measures with potential use in design and Human Factors. Measures such as sitting height, hip breadth, shoulder breadth, and others, are used to design and assess environments against the body sizes of its intended users.

The ideal scenario to obtain a detailed anthropometric dataset, that is also representative of the target population, is to perform a large scale survey, with a sample size order of magnitude of 10,000 or more, whilst also measuring all anthropometric dimensions of relevance. In the context of Human Factors, 30 or more dimensions can be used[1]. Collecting a large number of anthropometric measurements on a large sample size incurs large financial and time costs. As a result, such databases do not exist.

In practice, anthropometric surveys can be broadly divided in two categories:

- Large-scale surveys, with typical sample sizes of 10,000 or more, and few anthropometric measures – typically height, weight, and sometimes waist and/or hip circumference, with addition of the relevant demographic data (e.g. age, sex, postcode or state). Most national health surveys fall in this category, such as the NHS in Australia[2], NHANES in the USA[3], MikroZensus in Germany[4], or the Health Survey for England[5], and collect basic anthropometry as part of a larger population survey. Since such surveys are usually run by government agencies, their sample sizes and sampling strategies result in estimates that are representative of the countries' population.

- Detailed surveys, with typical sample sizes of 1,000, and a large number of anthropometric measures. These are usually targeting specific and narrow populations, and the intended target applications are related to Human Factors, ergonomics, and

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[1] Chaffin, D.B., Andersson, G.B. and Martin, B.J., 2006. *Occupational biomechanics*. John wiley & sons.

[2] Australia's National Health Survey

[3] USA's NHANES survey

[4] Germany's MikroZensus

[5] England's Health survey

performance. Such surveys include CAESAR[6], which provides approximately 100 individual measurements (as a mix of physical and 3D-scans measures) on 2,000 US citizens and 2,000 European citizens, or Australia's ASRAN[7] and AWAS[8] surveys, providing approximately 80 measurements on 1,200 Navy and 2,000 Army personnel, respectively.

For these reasons, multiple methods have been developed to enrich large-scale surveys in order to obtain estimates of detailed anthropometry on large scale, representative population samples (See Appendix 1 for details). In recent years, Kumar and Parkinson[9] and Reddie and Parkinson[10] have developed the so-called *nearest-neighbour reweighting method*, which when used on US data, proved to provide accurate estimates of population's anthropometry. We evaluated the suitability of the method when applied to Australian data with good results (Appendix 1) and therefore elected to use the nearest-neighbour reweighting method to obtain estimates of detailed, representative anthropometric measures for the Australian adults population. The NHS 2014 and 2017 surveys serve as the reference datasets, and the CAESAR US as the detailed dataset.

The reweighting method requires use of individual anthropometry data from the reference survey (NHS) as well as the detailed survey. The issue we encountered, however, is that data access rules from the Australian Bureau of Statistics (ABS) did not permit us to export NHS's individual anthropometry data. Likewise, while we were allowed to import individual CAESAR data into Datalab, we were not allowed to export the results of the reweighting method since the ABS still considered these as individual data and governed by their own legislation, as the data resided within the ABS environment, which researchers are required to use in order to access ABS data itself. As a result, we were not able to have both reference and detailed individual data in the same location to perform the reweighting.

To solve this issue, we elected to employ the following process:

- Within Datalab, where we had access to NHS's individual data, we fitted a statistical distribution to the anthropometric data. We then exported the distribution's parameters (ABS Output Clearance Request) outside of Datalab.
- Outside of Datalab, we reconstructed the distribution from its parameters.
- We then generated a synthetic individual dataset by sampling points from the distribution and validated it against the original ABS data
- This gave us simultaneous access to the synthetic reference dataset (generated from NHS's distribution fit) and the detailed dataset (CAESAR US).

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[6] CAESAR survey - volume 1

[7] Anthropometric Survey of the Royal Australian Navy (ASRAN).

[8] Australian Warfighter Anthropometry Survey (AWAS).

[9] Kumar, K.A. and Parkinson, M.B., 2018. Reweighting anthropometric data using a nearest neighbour approach. *Ergonomics*, *61*(7), pp.923-932.

[10] Reddie, M. and Parkinson, M.B., 2022. A comparison of approaches to reweighting anthropometric data. *Ergonomics*, *65*(10), pp.1397-1409.

Generating the reference NHS datasets

Fitting a skew normal distribution to the original NHS data

In order to obtain precise estimates of NHS individual anthropometry, the statistical distribution fitted must accurately represent the shape of the original distribution. Anthropometric data tends to be normally distributed. However, from the first part of this project (see Milestone 2 report), and general knowledge of population anthropometry data, it is widely accepted that weight data distribution displays a significant positive skew in developed countries (see e.g. De Onis et al.[11]). In other words, compared to an unskewed normal distribution, there are a significant number of individuals with weight measurements much larger than the mean. Other anthropometric measurements that correlate with weight (such as most circumferences) consequently also display a significant positive skew. Fitting a distribution that takes into account the positive skew in weight data is essential to generate a synthetic dataset that closely represents the actual Australian population. Additionally, it is essential to preserve the existing correlation between height and weight (i.e. taller individuals tend to also be heavier) to obtain representative data.

Most methods allowing fitting a multivariate skewed distribution to a dataset, such as Matlab's *skewnormal.m* or *pearsrnd.m*, or Python's *skewnorm.pdf*, provide numerical estimates of the density function at specified points. Using these would result in the output provided in bins of specified size, which would again be incompatible with the ABS's data output rules (or the bins would have to be too wide to provide sufficient granularity on the distribution).

Azzalini and colleagues[12] have provided the theoretical framework that presents the multivariate skew-normal distribution as an extension of the standard (unskewed) normal. Importantly, they provide methods by which a multivariate skew normal can be fitted to a given sample; with the ability to provide the result as the parameters of the analytical form of the distribution. This last point is critical since obtaining the analytical form of the distribution allows us to export it outside of Datalab while retaining the full detail of the distribution shape. In the publication mentioned above, they also provide an example of how the bivariate skew-normal can be used to fit anthropometric height-weight data. Finally, Azzalini et al. also developed an R package named *sn.r*[13], which provides the fitting and sampling functionality.

In Datalab, we first isolated height and weight data from the NHS 2014 and 2017 surveys, for all individuals aged 18-64, males and females separately. We then fitted a bivariate skew-normal distribution to these data and extracted the distribution parameters.

The bivariate height-weight distribution comprises 7 parameters:

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[11] De Onis, M. and Habicht, J.P., 1996. Anthropometric reference data for international use: recommendations from a World Health Organization Expert Committee. *The American journal of clinical nutrition*, *64*(4), pp.650-658.

[12] Azzalini, A. and Valle, A.D., 1996. The multivariate skew-normal distribution. *Biometrika*, *83*(4), pp.715-726.

[13] CRAN sn package.

- Mean (2 parameters: one for each of height and weight),
- Variance (2 parameters: one for each of height and weight),
- Covariance (1 parameter: the non-diagonal element of the covariance matrix),
- Skew (2 parameters: one for each of height and weight).

The first five parameters above are identical to a standard bivariate normal, and the two additional skew parameters define the skew of each variable (see Azzalini et al. for details).

Two distributions were fitted, for 18-64 years old males and females, separately. The respective sample sizes the distributions were fitted from were: male = 10,911; female = 12,568. The resulting distribution parameters are presented in Table 1 below. The values presented refer to the Centred Parameters (CP), which is the recommended parameterisation when dealing with anthropometry data[14] as it results in a better behaved log-likelihood function. The CP approach centres and normalises data before fitting the distribution, as such, the means and variances in Table 1 do not represent the means and variances of the NHS sample directly.

	Male	**Female**
Height mean	1746.85	1617.35
Weight mean	68.3409	51.049
Height variance	5985.04	4980.82
Weight variance	796.305	570.729
Height skew	-0.608695	-0.818159
Weight skew	3.300558	6.794833
Covariance	679.695	794.954

Table 1 - parameters of the fitted skew-normal distributions from NHS male and female height and weight data.

An ABS Output Clearance Request was then prepared, and the distribution parameters were released by the ABS. From this point on, the processing and analysis was performed outside the Datalab environment.

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[14] Arellano-Valle, R.B. and Azzalini, A., 2008. The centred parametrization for the multivariate skew-normal distribution. *Journal of multivariate analysis*, *99*(7), pp.1362-1382.

Generating individual data from the distribution

From these parameters, the corresponding distributions were recreated outside of Datalab, and sets of individual datapoints were generated from these, i.e., the synthetic individual datasets.

We first performed some tests on the dataset generation:

1. We assessed whether the sample size generated had an effect on the summary statistics of importance (e.g. median and percentiles). To achieve this, we generated multiple datasets with sample sizes ranging from 1,000 to 20,000.

2. Since individual data generation from the distribution performs a random sampling of datapoints, we tested whether multiple generations of datasets would present noticeable differences in summary statistics. To this effect we generated 1,000 synthetic samples with n=20,000 and compared the summary statistics.

3. Importantly, we quantified how well the synthetic datasets compared to the actual NHS data, in terms of height and weight percentiles.

4. Finally, we also tested how the generated data differed from a non-skewed normal distribution (to quantify the improvement over a non-skewed normal).

Effect of generated sample size

In order to assess the effect of the sample size generated from the distribution, we generated samples of 1,000, 5,000, 10,000 and 20,000 data points and compared height and weight percentiles for each. The results are presented in Table 2 below. “Source” refers to the percentiles computed from the original NHS 2014 and 2017 data, obtained in Milestone 2 of this project. These data correspond to sample sizes of approximately 10,000 for each of male and female.

Effect of generated sample size												
	Male 18-64						**Female 18-64**					
	Height (cm)			Weight (kg)			Height (cm)			Weight (kg)		
Percentile	5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
Source	163	176	188.4	63	85.2	120	151.7	163	174	50.3	69	107.9
n=1k	162.8	175.8	188.0	63.2	86.4	120.0	152.2	163.3	174.5	50.9	69.6	106.4
n=5k	163.6	176.0	188.4	63.0	85.6	119.5	151.0	162.7	174.2	50.6	69.9	106.4
n=10k	163.5	175.9	188.5	62.8	85.8	118.6	151.1	162.6	174.4	50.1	69.5	106.4
n=20k	163.6	176.0	188.6	63.2	85.9	119.5	151.3	162.7	174.2	50.3	70.3	107.0

Table 2 - effect of generated sample size on height and weight percentiles. “Source” refers to the NHS 2017-17 data.

Generated sample size does not appear to have a significant influence on the anthropometry data generated. For male, height data varied by 0.8cm at the 5th percentile (lowest: 162.8cm for n=1,000; highest: 163.6cm for n=5,000 and 20,000) and by 0.6cm at the 95th percentile (lowest: 188.0cm for n=1,000; highest: 188.6cm for n=20,000). Differences from the original NHS data were at most 0.6cm at the 5th percentile (n=20,000) and 0.4cm at the 95th percentile (n=1,000). Weight data varied by 0.4kg at the 5th percentile (lowest: 62.8kg for n=10,000; highest: 63.2kg for n=1,000 and 20,000) and by 1.4kg at the 95th percentile (lowest: 118.6kg, n=10,000; highest: 120.0kg, n=1,000) and differed from the original data by at most 0.2kg at the 5th percentile and 1.4kg at the 95th percentile. Results were similar for female data: height varied by 1.2cm at the 5th percentile and 0.3cm at the 95th percentile, depending on generated sample size, and largest differences from the original data were 0.7cm at the 5th percentile and 0.5cm at the 95th percentile. Weight data varied by 0.8kg at the 5th percentile and 0.6kg at the 95th percentile, and differed from the original NHS data by at most 0.6kg at the 5th percentile and 1.5kg at the 95th percentile.

Importantly, the results did not seem to follow a systematic trend toward increase or decrease with increasing sample size. The differences in height and weight values appeared to change somewhat randomly, and by relatively small amounts. As a result, it does not appear that the sample size chosen for synthetic data generation has a significant influence on the anthropometry values. We elected to use a sample size of 20,000 for the subsequent steps as it provided more granularity for the subsequent reweighting process.

Testing multiple generations of the artificial datasets

Since the synthetic datasets are generated as random samples from the distributions, the resulting statistical descriptives for anthropometry may vary with each generation. Assessing how much variability exists between different generations of individual data is important since one single generated dataset will be used in the subsequent reweighting process. We therefore wanted to assess how much variability exists between multiple generations of individual datasets. To achieve this, we generated 1,000 synthetic datasets with sample sizes of n=20,000, for males and females separately. We then computed the 1st, 5th, 50th, 95th and 99th percentiles for height and weight for each of the datasets generated this way. Finally, we computed the mean and median height and weight values at each of the percentiles over the 1,000 datasets. We also extracted the absolute minimum and maximum values of height and weight at each of the percentiles over all 1,000 generated datasets. Results are presented in Table 3 for males and Table 4 for females.

Variability over 1,000 dataset generations					
	Male 18-64 – Height (cm)				
	1st	5th	50th	95th	99th
Reference (NHS)	158	163	176	188.4	194
Min	157.6	163.1	175.8	188.2	193.1
Mean	158.2	163.5	176.0	188.5	193.7
Median	158.3	163.5	176.0	188.5	193.7
Max	159.0	163.8	176.2	188.9	194.3
SD	0.2	0.1	0.1	0.1	0.2

	Male 18-64 – Weight (kg)				
	1st	5th	50th	95th	99th
Reference (NHS)	54.9	63	85.2	120	142.9
Min	54.4	62.4	85.4	118.1	133.5
Mean	55.3	63.0	85.8	119.4	135.5
Median	55.3	63.0	85.8	119.4	135.5
Max	56.1	63.7	86.3	120.5	137.4
SD	0.3	0.2	0.1	0.3	0.6

Table 3 - variation in percentile values of height and weight over 1,000 generated datasets for the male population.

Variability over 1,000 dataset generations					
	Female 18-64 – Height (cm)				
	1st	5th	50th	95th	99th
Reference (NHS)	147	151.7	163	174	179
Min	145.9	150.8	162.5	173.9	178.5
Mean	146.4	151.2	162.7	174.2	179.0
Median	146.4	151.2	162.7	174.2	179.0
Max	147.0	151.5	162.9	174.5	179.5
SD	0.2	0.1	0.1	0.1	0.2

	Female 18-64 – Weight (kg)				
	1st	5th	50th	95th	99th
Reference (NHS)	45	50.3	69	107.9	130
Min	44.4	49.9	69.6	105.0	121.8
Mean	45.0	50.2	70.0	106.3	123.7
Median	45.0	50.2	70.0	106.3	123.7
Max	45.6	50.6	70.6	107.7	125.6
SD	0.2	0.1	0.2	0.4	0.7

Table 4 - variation in percentile values of height and weight over 1,000 generated datasets for the female population.

From the 5th to the 95th percentiles, the standard deviation for height is 1mm for both males and females, meaning 99.7% of the generated datasets are within ±3mm of the average generation. We can be confident that any generated dataset with n=20,000 will not deviate from the distribution in any significant manner, from the 5th to the 95th percentile. The 1st and 99th percentiles have a standard deviation for height of 2mm over the 1,000 dataset generations, for both males and females. which while higher than the more central percentiles, is still smaller than the usually mentioned values for measurement repeatability (see relevant section further down). Regarding the most extreme values generated: for weight, at the 1st percentile there is a 1.4cm and 1.1cm difference between the two most extreme datasets out of 1,000, for males and females respectively. At the 99th percentile, differences are similar: 1.2cm and 1.1cm for males and females respectively.

For weight data, once again the generation is stable up to the 5th and 95th percentiles, with a standard deviation of 0.1-0.4 kg depending on sex and percentile. At the 1st and 99th percentiles, the variability is slightly larger, up to 0.6kg and 0.7kg at the 99th percentile for males and females, respectively. It is worth noting that the weight estimates of the 95th percentile are slightly lower than the reference data (by approximately 0.5kg for males and 1.5kg for females). The standard deviation for the female 95th percentile is 0.4kg, meaning 99.7% of datasets generated will be within ±1.2kg of each other, or a roughly 1% deviation. The 1st percentiles are also very close to the reference data for both sexes and the standard deviation remains small. Therefore, and like height data, the weight data generated is stable across multiple generations from the distribution.

However, one should note that, at the 99th percentile for weight, the generated datasets significantly underestimate the weight: by 7.4kg for males and 6.3kg for females. This error appears to be systematic in that it occurred for all 1,000 datasets generated. This result is also seen in our final dataset (see below).

Overall, we can be confident that the height data generated from the distribution is stable and representative of the reference distribution.

Comparison with a non-skewed normal distribution

In order to quantify the improvement achieved by fitting a skew-normal, we compared the estimated percentiles from synthetic datasets generated with the skew-normal distribution (as above), and those generated with a non-skewed distribution, i.e. a standard, symmetric bivariate normal distribution. We generated one sample for each of males and females, with sample size n=20,000. The first sample (“skewed”) was generated using the skew normal distribution described above; the second sample (“unskewed”) was generated with a standard bivariate normal distribution. Results are presented in Table 5.

Skewed versus unskewed data generation					
	Male 18-64– Height (cm)				
	1st	5th	50th	95th	99th
Reference (NHS)	158	163	176	188.4	194
Skewed	158.2	163.5	176.0	188.5	193.7
Unskewed	158.0	163.4	176.0	188.5	193.9
	Male 18-64– Weight (kg)				
	1st	5th	50th	95th	99th
Reference (NHS)	54.9	63	85.2	120	142.9
Skewed	55.3	63.0	85.8	119.4	135.5
Unskewed	26.2	44.3	87.5	130.4	147.5
	Female 18-64– Height (cm)				
	1st	5th	50th	95th	99th
Reference (NHS)	147	151.7	163	174	179
Skewed	146.4	151.2	162.7	174.2	179.0
Unskewed	146.9	151.6	163.1	174.6	179.4
	Female 18-64– Weight (kg)				
	1st	5th	50th	95th	99th
Reference (NHS)	45	50.3	69	107.9	130
Skewed	45.0	50.2	70.0	106.3	123.7
Unskewed	4.2	22.3	69.3	115.3	133.8

Table 5 – Percentiles for height and weight data generated from a skewed and unskewed normal distribution, as well as NHS reference data.

For height data, the non-skewed distribution percentile values are extremely close to the skewed values, and both skewed and unskewed data closely match the reference. This is somewhat expected since height data only presents a small skew (Table 1). However, weight data at the extreme percentiles is highly unrealistic when generated from the non-skewed distribution. Most notably, the lowest percentiles (1st and 5th) are very significantly underestimated. The non-skewed distribution, by definition, has equal interquartile ranges on the left and right sides of the median (e.g. in our case, both the 1st and 99th male percentiles are approximately 60kg from the median), so the fit results in large underestimation of the lowest percentiles, as well as an overestimation of the highest percentiles. The effect is even larger for females, since female data has a larger skew than male data. Overall, it appears clear from the weight percentiles that including the skew is required for an acceptable fit.

Comparison of the final synthetic dataset to reference NHS data

Given the results above, the final synthetic datasets were generated using the bivariate normal distribution whose coefficients are presented in Table 1, using a sample size of n=20,000, for 18-64 years old males and females separately.

Final synthetic NHS datasets – comparisons to NHS reference												
	Male 18-64						**Female 18-64**					
	Height (cm)			Weight (kg)			Height (cm)			Weight (kg)		
	5th	**50th**	**95th**	**5th**	**50th**	**95th**	**5th**	**50th**	**95th**	**5th**	**50th**	**95th**
Reference	163	176	188.4	63	85.2	120	151.7	163	174	50.3	69	107.9
Generated.	163.1	176.1	188.7	63.5	85.5	119.2	151.2	162.5	174.4	50.1	69.8	106.4
Difference	0.1	0.1	0.3	0.5	0.3	-0.8	-0.5	-0.5	0.4	-0.2	0.8	-1.5
Diff. %	< 0.1	< 0.1	0.2	0.8	0.4	-0.7	0.3	0.3	0.2	0.4	1.2	-1.4

Table 6 - comparison of the generated individual datasets to hte reference data (NHS).

Like the results presented in the sections above, the synthetic datasets are extremely close to the original NHS values. Of note however, is the systematic underestimation of weight data at the 95th percentiles. For males, 95th percentile weight is underestimated by 0.8kg (0.7%), and for females by 1.5kg (1.4%). And as shown in the section above, this underestimation gets more severe at the 99th percentiles (approximately 7kg for both males and females, see Table 3 and Table 4). These differences at the 99th percentile are expected to, in turn, cause significant differences in the estimates of anthropometric dimensions related to weight, such as most circumferences.

Reweighting the NHS dataset

For the sake of brevity, the *synthetic* NHS datasets generated using the methods described in the section above will be referred to as simply “NHS datasets” from here on.

Details and evaluation of the nearest-neighbour reweighting process are provided in Appendix 1. We only here provide a summary of the method and relevant results.

CAESAR dataset

The US part of the CAESAR dataset is used as the detailed dataset in the reweighting process. CAESAR comprises 105 anthropometric measurements (physical and digital) for 1,114 males (age 18-64) and 1,252 females (age 18-64). Table 7 below provides a summary comparison of CAESAR and NHS datasets.

NHS – CAESAR comparison												
	Male 18-64						**Female 18-64**					
	Height (cm)			Weight (kg)			Height (cm)			Weight (kg)		
	5th	50th	95th	5th	50th	95th	5th	50th	95th	5th	50th	95th
NHS	163.1	176.1	188.7	63.5	85.5	119.2	151.2	162.5	174.4	50.1	69.8	106.4
CAESAR	164.6	177.5	191.2	63.7	83.3	119.7	152.4	163.7	176.8	49.7	65.1	104.1
difference	1.5	1.4	2.5	0.2	-2.2	0.5	1.2	1.2	2.4	-0.4	-4.7	-1.6

Table 7 - comparison of height and weight data for the synthetic NHS and teh CAESAR detailed datasets.

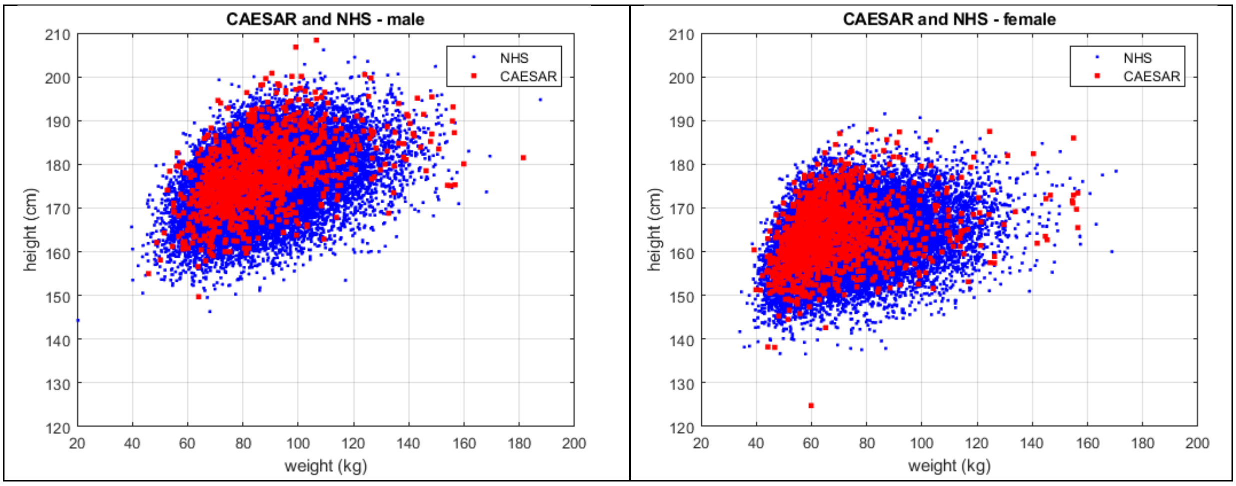

Figure 2 - overview of the NHS and CAESAR individual data.

Figure 2 above also provides a visual representation of the overlap of the NHS (blue) and CAESAR (red) datasets, where each individual data point is shown.

From this figure it appears that the female NHS weight data has a larger right skew than the male data. This is also indicated by the weight skew coefficient of the distribution being larger for females than males (Table 1). However, reports from the Australian Institute of Health and Welfare (AIHW) indicate more prevalence of overweight and obesity in males, compared to females[15]. It may be of interest to compute BMI for the NHS data to check against these observations:

	Male	Female
BMI > 25 (overweight)	71% (AIHW: 75%)	59% (AIHW: 60%)
BMI > 30 (obese)	32% (AIHW: 33%)	31% (AIHW: 30%)
BMI > 35	10%	13%
BMI > 40	2%	4%

Table 8 - comparison of overweight and obesity rates obtained from NHS data and as reported by AIHW.

Note that the quoted AIHW data relates to Australian aged 18 and over, while our NHS data is for ages 18-64. The AIHW states that overweight and obesity rates tend to increase with age. The table above confirms our findings: while more males overall are overweight and/or obese than females, the skew in weight data is greater in females, and there are more females overall with BMI>35 than males.

The reweighting process

The reweighting process was applied to the NHS dataset (reference dataset), using CAESAR as the detailed dataset. The process was performed for male and female data separately.

Details and assessment of the reweighting process are described in Appendix 1. Briefly, it involves the following steps:

1. For each of the reference and detailed datasets, normalise the height and weight data to the range (maximum minus minimum) of height and weight data in the reference dataset.

2. For each individual point in the reference dataset, find its corresponding nearest neighbour in the detailed dataset. Nearest neighbour means the point with the smallest Euclidean distance in the 2D normalised height-weight space.

3. Each individual point in the detailed dataset gets a weighting of 1 for each point in the reference dataset it is the nearest neighbour of.

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[15] https://www.aihw.gov.au/reports/australias-health/overweight-and-obesity

4. After all weightings have been assigned (i.e. all points in the reference dataset have gone through Step 2), identify the points in the detailed dataset with a weighting of 0.

5. For each 0-weighting point identified in Step 4, find its nearest neighbour in the detailed dataset.

6. Redistribute the weights evenly between the 0-weighting points and their nearest neighbours. For instance, if a (non-zero-weighting) point has a weighting of 12 after Step 3, and two, 0-weighting neighbours after Step 4, then each of these three points get a weighting of 4 (12/3) after Step 6.

The goal of Steps 4 to 6 above is to have all individual points from the detailed dataset have some influence on the whole reweighting process, thus preserving the variability in anthropometry present in the initial detailed dataset[16]. Note that, prior to Step 4, all weightings were multiplied by 100. This was done to improve the precision of the reweighting process, since the rebalancing in Steps 4-6 can result in fractional weightings, while integer weightings are needed to subsequently generate the reweighted dataset and compute percentiles. Multiplying weightings by 100 effectively allows fractional weights with up to 2 decimal places. This approach was also used by Kumar and Parkinson for US data. These weightings are also those provided in Appendix 2 (full reweighted anthropometry dataset).

Figure 3 below displays the weightings assignment before (left) and after (right) the rebalancing process (Steps 4-6) was applied to the male dataset. We can observe that:

- Most CAESAR data points have weightings between 0 and 20. This is desirable since it indicates that most CAESAR individuals contribute in a relatively even manner to the final reweighted dataset, preserving as much of the intra-individual variability in anthropometry as possible.

- Likewise, the fact that very few data points (18/1,114) had a weighting of 0 before the rebalancing process is also desirable, since it indicates the vast majority of CAESAR individuals contribute to the final dataset, again preserving most of the variability present in the original CAESAR anthropometric data.

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[16] Kumar, K.A. and Parkinson, M.B., 2018. Reweighting anthropometric data using a nearest neighbour approach. *Ergonomics*, *61*(7), pp.923-932.

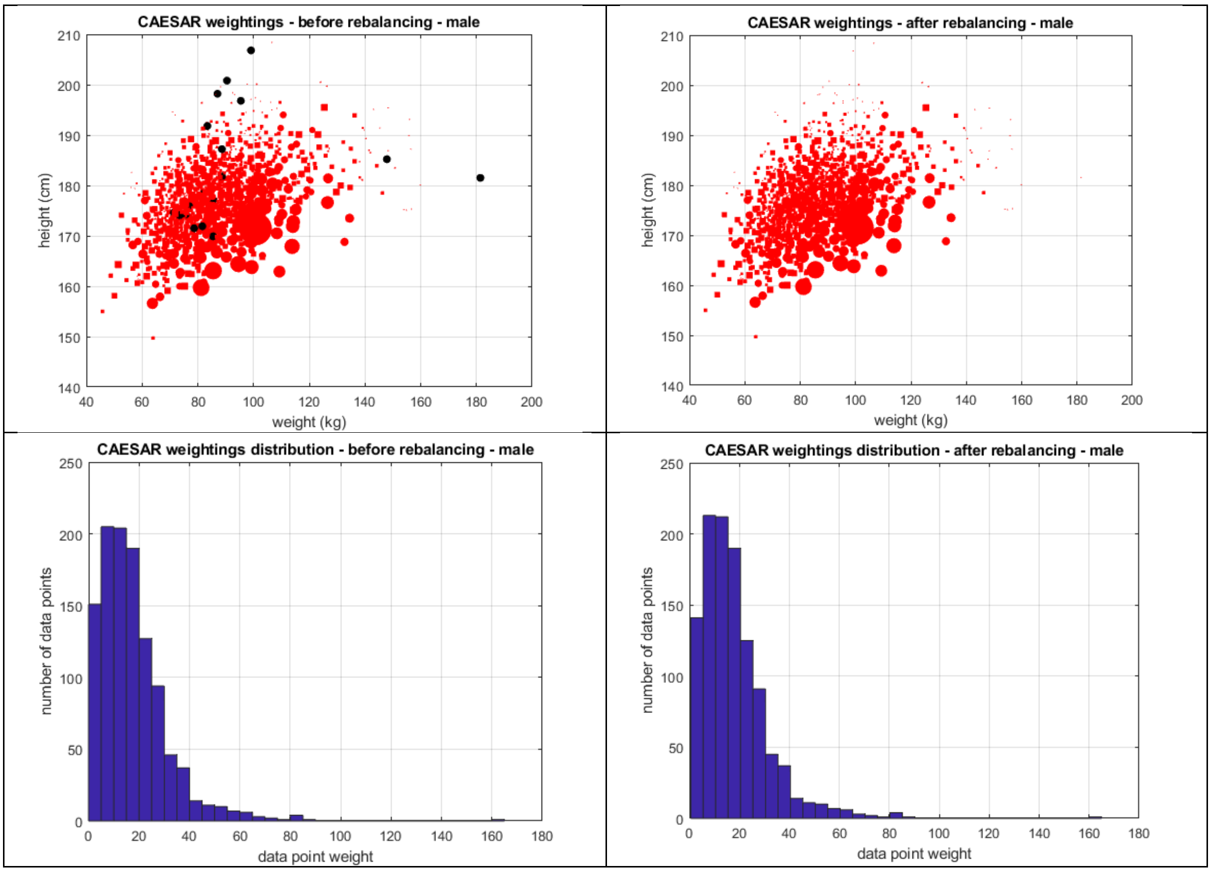

Figure 3 – top: weightings distribution among individual CAESAR male datapoints, before (left) and after (right) the rebalancing process. The size of each marker is proportional to the weighting assigned to it. Datapoints with 0 weighting assigned are marked in black (top left) Bottom: histogram of weightings distribution before (left) and after (right) the weighting redistribution.

The univariate percentile values for each anthropometric dimension were then computed from the reweighted dataset. These are presented in the following section.

The detailed Australian anthropometry datasets

This section presents the main goal of the present project, which is the detailed univariate anthropometric dataset of Australian adults aged 18-64.

Data are presented separately for males and females. We elected to present here the percentiles most commonly used in Human Factors, that is, the 1st, 5th, 50th, 95th and 99th percentiles. We also present the 25th and 75th percentiles in order to quickly estimate the interquartile ranges.

Although the full detailed dataset contains 105 individual anthropometric measurements, we only present here a more limited selection of 43 measurements. This selection was based on the most used anthropometric dimensions in a Human Factors context. We based this in part on the results of the stakeholders interviews (Milestone 2 report), and in part on some previous Defence work[17], where 27 dimensions were identified and selected as core dimensions included in the boundary manikin creation process.

Results below are presented into four separate tables, grouped by broad anthropometry categories: standing heights and lengths; standing circumferences, breadths, and widths; sitting measurements; and clothing-related measurements. Each table is accompanied by illustrations depicting the corresponding measurements, allowing for quick identification. For a full reference on the measurement protocol for each measure, please refer to the CAESAR report[18].

Finally, while we were unable to reweigh children data, due to the absence of a detailed children anthropometry database, we present the NHS height and weight data for children aged 2-18 years old, to serve as reference. These data were obtained during the first stage of the project.

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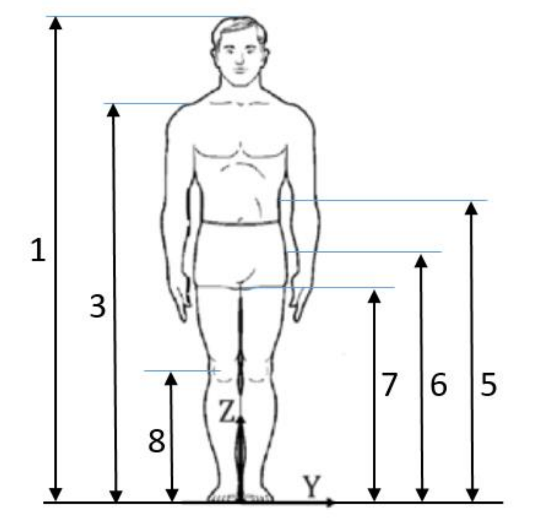
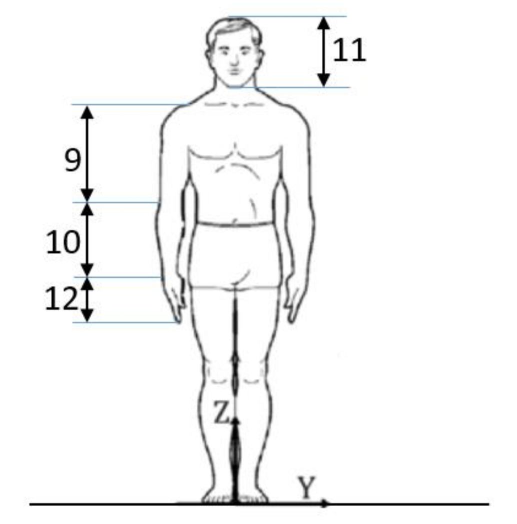
[17] Anthropometric Survey of the Royal Australian Navy (ASRAN).

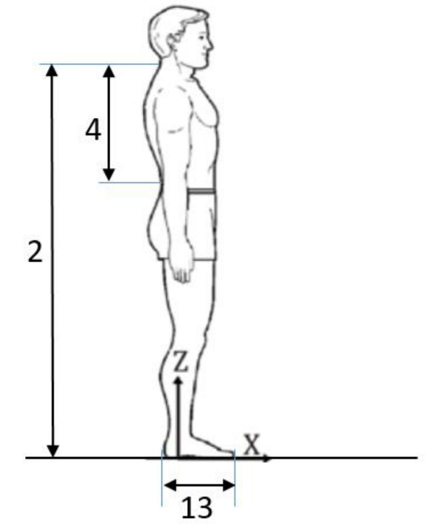
[18] CAESAR survey - volume 1.

NHS detailed anthropometry - adults 18-64 years old
Standing measurements – heights and lengths

	Males							Females						
Percentile	**1st**	**5th**	**25th**	**50th**	**75th**	**95th**	**99th**	**1st**	**5th**	**25th**	**50th**	**75th**	**95th**	**99th**
1. Stature	159.7	163.1	170.8	176.1	181.2	188.7	194.0	147.4	151.5	157.9	162.5	167.5	174.2	179.3
2. Cervicale height	135.4	140.6	147.0	152.0	156.8	163.8	168.6	125.8	129.8	135.4	139.8	144.2	150.2	155.2
3. Acromion height	128.3	133.3	139.6	144.7	149.1	156.5	160.3	118.9	123.1	129.5	133.6	137.9	143.9	148.4
4. Back length (waist back)	40.2	42.2	45.1	47.6	50.0	53.5	56.1	33.9	35.1	37.6	39.4	41.0	44.0	46.6
5. Waist height	89.6	94.0	99.3	103.0	107.3	112.5	116.5	88.9	91.4	96.5	100.3	103.7	109.5	113.3
6. Hip height (at max. circ.)	75.1	79.2	84.3	88.2	91.6	97.0	102.8	69.8	72.9	77.4	81.2	86.1	93.8	98.1
7. Crotch height	67.0	70.4	75.6	79.1	82.6	87.4	91.5	63.8	66.4	70.9	73.9	76.9	81.4	84.6
8. Knee height standing	42.6	44.6	47.2	49.1	51.2	53.7	56.0	38.8	40.1	42.3	44.0	45.9	48.4	49.9
9. Acromion-radiale length	27.9	29.5	31.3	32.6	34.0	35.8	36.8	25.7	27.1	28.6	29.8	31.1	32.9	34.5
10. Radiale-stylion length	23.0	24.0	25.3	26.2	27.4	29.0	30.6	20.5	21.5	22.7	23.7	24.7	26.1	27.3
11. Head length	18.3	18.7	19.6	20.0	20.5	21.3	21.8	17.0	17.6	18.3	18.8	19.3	19.9	20.3
12. Hand length	17.9	18.6	19.5	20.2	20.9	22.0	23.1	16.1	16.6	17.4	18.1	18.8	19.8	20.8
13. Foot length	23.2	24.4	25.7	26.6	27.7	29.0	30.4	21.3	22.0	23.0	23.9	24.8	25.9	27.0
14.Thumb tip reach	71.4	73.6	77.8	80.6	83.8	87.5	91.0	65.2	67.8	70.7	73.6	76.3	79.7	83.1

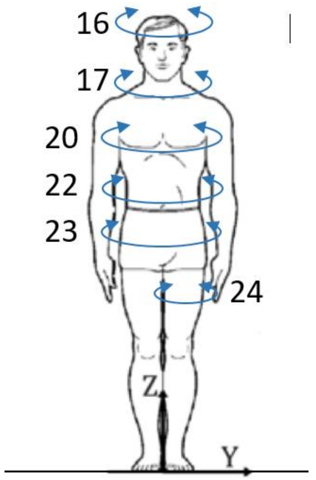


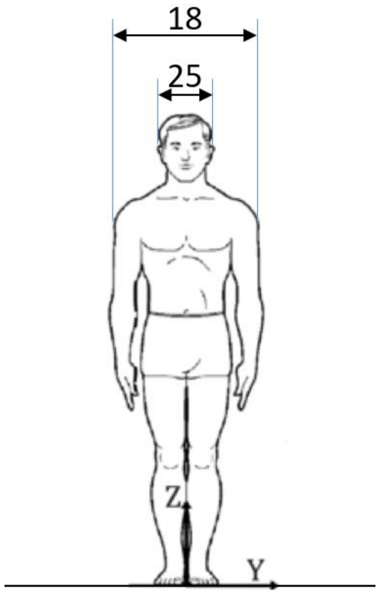


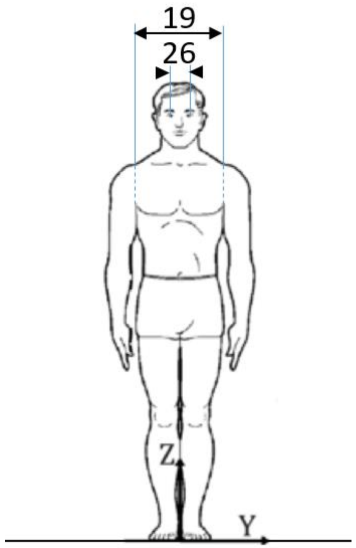


NHS detailed anthropometry - adults 18-64 years old
Standing measurements – weight, circumferences, breadths, and widths

	Males							Females						
Percentile	**1st**	**5th**	**25th**	**50th**	**75th**	**95th**	**99th**	**1st**	**5th**	**25th**	**50th**	**75th**	**95th**	**99th**
15. Weight	56.2	63.5	75.3	85.5	98.0	118.1	134.7	45.1	50.3	59.6	69.8	83.4	105.7	121.3
16. Head circumference	54.4	55.3	56.8	57.9	58.9	60.7	61.7	52.0	52.5	54.0	55.3	56.5	58.5	60.2
17. Neck circumference	40.9	42.5	44.9	46.7	48.7	52.1	55.1	36.1	37.4	39.5	41.2	43.0	46.9	49.2
18. Shoulder breadth	42.5	44.2	47.5	49.7	52.2	55.6	59.0	37.2	38.7	41.2	43.2	45.9	49.8	54.5
19. Back width	34.2	35.7	38.2	40.3	42.2	44.8	47.7	30.4	32.1	34.3	36.2	38.8	42.5	45.1
20. Chest circumference	84.3	88.8	97.6	104.2	112.1	122.8	135.3	78.4	82.2	90.0	96.9	108.2	123.0	137.1
21. Chest circ. under bust								66.7	69.5	75.2	80.4	88.5	101.5	110.2
22. Waist circumference	70.0	75.8	84.5	90.9	99.3	115.1	131.1	61.1	64.1	72.1	79.7	91.5	107.7	119.8
23. Hip circumference	87.2	92.3	99.3	104.7	111.0	121.6	131.3	88.2	91.7	98.9	106.6	116.1	133.3	143.7
24. Thigh circumference	47.7	52.5	57.3	61.1	65.3	73.1	78.1	48.6	51.6	56.7	61.7	67.7	77.3	82.0
25. Head breadth	14.2	14.6	15.2	15.6	15.9	16.6	17.2	13.4	13.8	14.4	14.7	15.1	15.7	16.2
26. Inter-pupillary distance	5.7	5.9	6.4	6.8	7.2	7.8	8.3	5.3	5.8	6.3	6.6	7.0	7.5	7.9

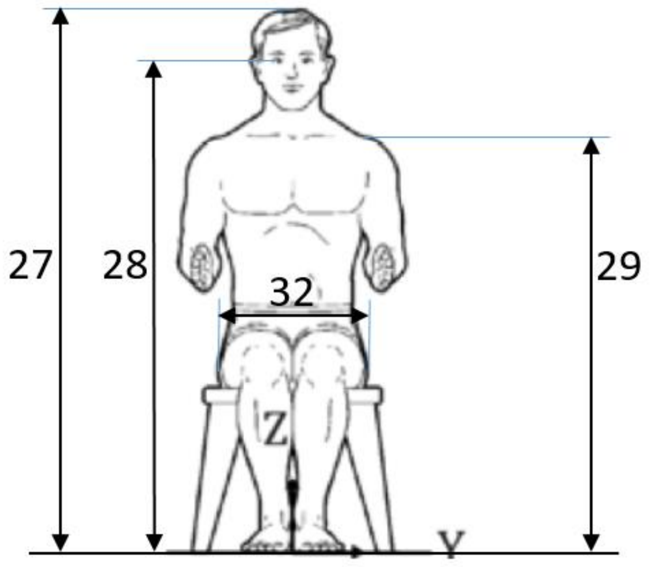


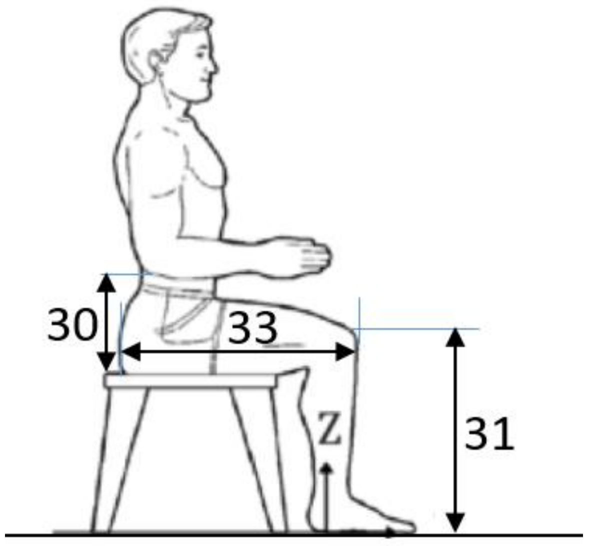


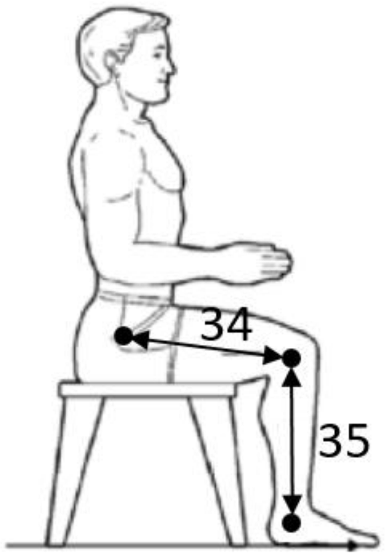


NHS detailed anthropometry - adults 18-64 years old
Sitting measurements

	Males							Females						
Percentile	**1st**	**5th**	**25th**	**50th**	**75th**	**95th**	**99th**	**1st**	**5th**	**25th**	**50th**	**75th**	**95th**	**99th**
27. Sitting height	82.7	85.1	89.1	91.8	94.5	98.0	101.4	77.2	80.1	83.7	85.9	88.1	91.8	94.4
28. Eye height sitting	71.5	73.7	77.7	80.1	82.6	86.1	89.1	66.9	69.5	72.8	74.9	77.2	80.5	83.3
29. Acromion height sitting	53.1	54.7	57.9	60.3	62.6	65.5	67.6	49.9	51.9	54.5	56.5	58.5	61.2	63.8
30. Elbow height sitting	17.5	19.1	22.1	24.1	26.2	28.9	30.4	17.3	19.4	21.8	23.6	25.4	28.0	30.4
31. Knee height sitting	48.3	50.8	53.6	55.7	57.8	60.5	63.3	44.8	46.2	48.7	50.4	52.6	55.0	57.1
32. Hip breadth sitting	31.1	33.4	36.1	38.1	40.6	44.6	48.1	33.8	35.2	38.3	41.4	44.9	50.7	53.7
33. Buttock-knee length	53.4	55.9	59.5	61.6	63.6	67.2	70.2	50.8	53.0	56.4	58.6	61.6	64.9	68.8
34. Thigh length	37.0	38.9	41.7	43.5	45.2	47.7	49.6	34.6	36.4	39.0	41.0	42.8	45.5	47.4
35. Shank length	35.2	36.8	38.9	40.6	42.3	44.5	46.5	32.5	33.3	35.2	36.7	38.2	40.3	41.8







NHS detailed anthropometry - adults 18-64 years old
Clothing related measurements

	Males							Females						
Percentile	**1st**	**5th**	**25th**	**50th**	**75th**	**95th**	**99th**	**1st**	**5th**	**25th**	**50th**	**75th**	**95th**	**99th**
36. Sleeve outseam	50.7	52.7	55.6	57.7	60.0	62.9	65.3	46.3	48.0	50.2	52.2	54.4	57.4	59.3
37. Spine-wrist length	76.6	79.2	83.1	85.5	88.3	92.4	95.2	69.6	71.8	74.8	77.5	80.2	83.9	86.4
38. Shoulder-wrist length	56.4	58.5	61.7	63.8	66.3	69.9	72.5	51.1	53.0	55.7	58.0	60.4	63.6	65.5
39. Shoulder-elbow length	28.8	30.5	32.3	33.6	35.0	37.3	38.8	27.0	28.1	29.9	31.2	32.6	34.4	36.3
40. Arm inseam	39.3	40.4	43.0	45.1	47.4	50.2	52.2	35.4	37.3	40.1	41.8	43.9	46.8	48.4
41. Armscye circumference	37.0	39.0	42.6	45.1	47.9	52.5	54.8	31.9	33.5	36.6	39.1	42.6	48.5	51.4
42. Trunk circumference	153.1	156.3	165.4	171.7	179.2	190.3	198.6	139.6	144.1	151.7	158.2	165.9	179.5	185.8
43. Crotch length	54.3	57.3	61.7	64.7	68.7	78.0	84.8	54.5	59.2	66.3	70.8	75.8	83.3	88.1

NHS basic anthropometry – boys (2-17 years old)

Percentile		1st	5th	10th	25th	50th	75th	90th	95th	99th
2-3 years old	Weight (kg)	11.3	12.3	12.8	14	15.3	17	19	20	22.6
n = 575	Height (cm)	81.3	86	88	91.2	96.9	101	105	107	108.9
	Waist circumference (cm)	41	45	46	49	52	54	56	57	63
4-5 years old	Weight (kg)	14	15.4	16.3	18	20	22.6	27.4	31	42.5
n = 585	Height (cm)	97	100	102	106	111	117	125	134.5	144.6
	Waist circumference (cm)	44	47	49	52	55	58	62	66.9	70.3
6-7 years old	Weight (kg)	16.6	18.8	19.9	22	24.7	29.1	34.8	38	44.4
n = 507	Height (cm)	105	111	113	119	124	130	135	139	143.9
	Waist circumference (cm)	47	50	51	54	57	61.2	68	72	79.9
8-9 years old	Weight (kg)	17.9	20.4	22.1	25.5	30.1	35.6	42	47	54.6
n = 524	Height (cm)	106.2	113.7	119	127	132.6	139	144	146.8	151.3
	Waist circumference (cm)	48	51	53	56.9	60	67	73.3	77	89.6
10-11 years old	Weight (kg)	25.5	29.3	30.5	33.9	40.4	49	57.4	61.8	75.6
n = 486	Height (cm)	127.4	133.2	136	141	146.7	152	157	158.9	165.8
	Waist circumference (cm)	52.9	56	58	61.5	67	75	83	88.8	96.1
12-13 years old	Weight (kg)	32.5	36.6	38.5	44	51.8	60.2	73.9	82.4	98
n = 466	Height (cm)	140.7	146	148.4	153.1	160.3	167.5	173.5	177.9	183.4
	Waist circumference (cm)	53.9	60	61.9	66.1	72	80	91.8	99	115
14-15 years old	Weight (kg)	35.3	41.9	45.5	53	61.5	71.3	83.4	90	104.9
n = 546	Height (cm)	145.1	152.3	157.1	165	171.1	177	183	185.5	189.2
	Waist circumference (cm)	57.5	63	65	70	76	84.5	93	97.8	109.1
16-17 years old	Weight (kg)	47.8	52.3	55.2	61.8	70.6	82.2	94.8	103	126.3
n = 590	Height (cm)	158	163	167	171	176.5	182.5	187	188.4	192.2
	Waist circumference (cm)	62.9	67.4	70	74	79	89	99	104.5	119.3

NHS basic anthropometry – girls (2-17 years old)

Percentile		**1st**	**5th**	**10th**	**25th**	**50th**	**75th**	**90th**	**95th**	**99th**
2-3 years old	Weight (kg)	9.9	11.4	11.8	13.2	14.8	16.1	18	19.4	26.3
n = 550	Height (cm)	76.5	84	86	89.6	95	99.7	104	106	110
	Waist circumference (cm)	39.5	45	45	48	50	53	56	59	65
4-5 years old	Weight (kg)	13.2	15.3	16.1	17.6	19.8	22.8	28	33.3	41.3
n = 569	Height (cm)	94.4	99.6	101.9	106	111	117	126.1	132.7	142.1
	Waist circumference (cm)	44	47	49	51	54.3	58	63	68	76.6
6-7 years old	Weight (kg)	16.6	18.1	19	21.2	24	28.8	34.5	40	46.4
n = 465	Height (cm)	103.8	108.6	111	116.5	123	129	134	139.3	148.1
	Waist circumference (cm)	44.6	48	50	53	56.6	61	67	72.4	82
8-9 years old	Weight (kg)	17.4	19.3	21	24	28.3	34.2	41	45	50.1
n = 454	Height (cm)	105.3	112	115.5	123	131	136.8	143	147	153.2
	Waist circumference (cm)	46	50.3	52	55	59.5	65.2	70.2	75.3	81.5
10-11 years old	Weight (kg)	25.1	29.1	30.6	34	39.7	46.5	54.1	58.1	77.6
n = 459	Height (cm)	130	134	137	142	147.5	153	157	160	164.4
	Waist circumference (cm)	50	54.5	56	59	65	71	77.5	81	96.9
12-13 years old	Weight (kg)	33.9	35.5	40.2	44	50.4	58.3	68	75	89.1
n = 436	Height (cm)	138.4	143.5	148.3	153	158	163	168	170	175
	Waist circumference (cm)	56	60	61	64	68.9	75.5	84	87.5	103.2
14-15 years old	Weight (kg)	36.1	41.2	44.3	50.8	57.2	66	79	86.2	106.7
n = 503	Height (cm)	146	151	153	158	163	167	171.1	174.9	179
	Waist circumference (cm)	57	60	62.1	66	72	79	89	95	106
16-17 years old	Weight (kg)	40.1	46.4	49	54.1	60.7	68.6	79.2	87.2	108.1
n = 607	Height (cm)	149	153	155	159	164	169.4	173	175	179
	Waist circumference (cm)	58.1	63	65	69	73	81	88	94	111.1

Comparison to PeopleSize Australian data

NHS detailed versus PeopleSize Australian data – 18-64 years old							
		Males			Females		
Percentile		**5th**	**50th**	**95th**	**5th**	**50th**	**95th**
Stature	NHS	163.1	176.1	188.7	151.5	162.5	174.2
	PeopleSize	165.6	176.9	188.2	153	163.2	173.5
	Difference	2.5 (1.5%)	0.8 (0.4%)	-0.5 (-0.2%)	1.5 (0.9%)	0.7 (0.4%)	-0.7 (-0.4%)
Weight	NHS	63.5	85.5	118.1	50.3	69.8	105.7
	PeopleSize	67	84	110	52	69	98
	Difference	3.5 (5.5%)	-1.5 (-1.7%)	-8.1 (-6.8%)	1.7 (3.3%)	-0.8 (-1.1%)	-7.7 (-7.2%)
Sitting height	NHS	85.1	91.8	98.0	80.1	85.9	91.8
	PeopleSize	86.5	88.8	99	76.8	82.4	91.9
	Difference	1.4 (1.6%)	-3 (-3.2%)	1 (1%)	-3.3 (-4.1%)	-3.5 (-4%)	0.1 (0.1%)
Waist height	NHS	94.0	103.0	112.5	91.4	100.3	109.5
	PeopleSize	99.7	108.4	117.1	94	101.5	109
	Difference	5.7 (6%)	5.4 (5.2%)	4.6 (4%)	2.6 (2.8%)	1.2 (1.1%)	-0.5 (-0.4%)
Knee height	NHS	44.6	49.1	53.7	40.1	44.0	48.4
	PeopleSize	44.7	49.1	53.5	41	45.1	49.2
	Difference	0.1 (0.2%)	0 (0%)	-0.2 (-0.3%)	0.9 (2.2%)	1.1 (2.5%)	0.8 (1.6%)
Buttock-knee length	NHS	55.9	61.6	67.2	53.0	58.6	64.9
	PeopleSize	57.3	62.4	67.7	54.3	59.4	64.7
	Difference	1.4 (2.5%)	0.8 (1.2%)	0.5 (0.7%)	1.3 (2.4%)	0.8 (1.3%)	-0.2 (-0.3%)
Shoulder breadth	NHS	44.2	49.7	55.6	38.7	43.2	49.8
	PeopleSize	44	47.9	52.2	40.3	45	50.4
	Difference	-0.2 (-0.4%)	-1.8 (-3.6%)	-3.4 (-6.1%)	1.6 (4.1%)	1.8 (4.1%)	0.6 (1.2%)
Hip breadth sitting	NHS	33.4	38.1	44.6	35.2	41.4	50.7
	PeopleSize	34.6	38.9	43.6	35.1	40.5	47.1
	Difference	1.2 (3.5%)	0.8 (2%)	-1 (-2.2%)	-0.1 (-0.2%)	-0.9 (-2.1%)	-3.6 (-7.1%)
Chest circumference	NHS	88.8	104.2	122.8	82.2	96.9	123.0
	PeopleSize	94.1	106.2	120.5	84.3	95.8	110
	Difference	5.3 (5.9%)	2 (1.9%)	-2.3 (-1.8%)	2.1 (2.5%)	-1.1 (-1.1%)	-13 (-10.5%)
Chest circ. Under bust	NHS				69.5	80.4	101.5
	PeopleSize				74.3	84.1	96.2
	Difference				4.8 (6.9%)	3.7 (4.6%)	-5.3 (-5.2%)
Waist circumference	NHS	75.8	90.9	115.1	64.1	79.7	107.7
	PeopleSize	81.9	97.7	118	67.3	83.9	108.1
	Difference	6.1 (8%)	6.8 (7.4%)	2.9 (2.5%)	3.2 (4.9%)	4.2 (5.2%)	0.4 (0.3%)
Hip circumference	NHS	92.3	104.7	121.6	91.7	106.6	133.3
	PeopleSize	92.1	103.1	115.6	88.6	102.7	121.2
	Difference	-0.2 (-0.2%)	-1.6 (-1.5%)	-6 (-4.9%)	-3.1 (-3.3%)	-3.9 (-3.6%)	-12.1 (-9%)

Table 9 - comparison of the detailed anthropometric data with values provided by PeopleSize. Errors greater than 3% are highlighted in yellow, errors greater than 5% are highlighted in orange.

In the initial phase of the project, end-user interviews highlighted that the PeopleSize software was the most used reference database for Australian anthropometry. However, the interviews also revealed that the level of confidence in the data provided by PeopleSize was low. For this reason, we provide here a comparison of the detailed Australian anthropometry dataset obtained here, with values provided by PeopleSize for Australian adults (Table 9**Error! Reference source not found.**).

At the 50th percentile, PeopleSize estimates are relatively close to the NHS data. Stature differs by 0.8 and 0.7cm for males and females, respectively, which is only marginally larger than typical measurement errors due to repeatability and due to the reweighting process. Similarly, weight differs by -1.5 and -0.8kg for males and females respectively, which is under a 2% relative error. Of note, PeopleSize tends to systematically underestimate weight, as well as other dimensions associated to weight (e.g. circumferences), even at the 50th percentile.

At the 5th percentile, for males, PeopleSize tends to overestimate heights and lengths. Stature is overestimated by 2.5cm (1.5%) which is noticeably larger than measurement errors. Likewise, waist height is overestimated by 5.7cm and buttock-to-knee length by 1.4cm. For weight, breadths and circumferences, the overestimation by PeopleSize is even more significant. Weight is overestimated by 3.5kg (5.5%), chest circumference by 5.3cm (5.9%), waist circumference by 6.1cm (8%). For females, heights and lengths tend to be closer to NHS data than for males: stature is overestimated by 1.5cm (0.9%), sitting height underestimated by 3.3cm (4.1%). There is overall a small trend toward overestimation of heights and lengths for females. For weight, breadths and circumferences, there is a trend for overestimation compared to NHS, with relatively large differences: weight, shoulder breadth, chest circumference under bust, and waist circumference are overestimated by 1.7kg (3.3%), 1.6cm (4.1%), 4.8cm (6.9%) and 3.2cm (4.9%). Hip circumference is underestimated, by 3.1cm (3.3%).

Overestimating anthropometric dimensions for the low percentiles can lead to issues in design assessment, since the boundary users are thought to be overall larger in size than in reality. This can lead to over-dimensioned designs that do not actually accommodate the lower percentile individuals. In that sense, the tendency for PeopleSize to overestimate anthropometry at the low percentiles can potentially be detrimental. (Underestimating the low percentiles may lead to overshooting the accommodation target, which is potentially less detrimental since more individuals are accommodated; however, it can create more strain on the design constraints).

At the 95th percentile, for males, heights and lengths estimates are overall close to NHS data. The only noticeable deviation is waist height, overestimated by 4.6cm (4%). Stature is within 0.5cm (0.2%), sitting height within 1cm (1%), knee height 0.2cm (0.3%) and buttock-to-knee length 0.5cm (0.7%). However, weight is largely underestimated, by 8.1kg (6.1%), and so is shoulder breadth (-3.4cm, -6.1%) and hip circumference (-6cm, -4.9%). For females, the same trend is observed. While heights and lengths are reasonably close to NHS values (stature: -0.7cm (-0.4%), sitting height 0.1cm (0.1%), knee height 0.8cm (1.6%), buttock-to-knee length -

0.2cm (-0.3%)), weight and circumferences are heavily underestimated. Weight is underestimated by 7.7kg (7.2%), sitting hip breadth by 3.6cm (7.1%), and chest circumference, chest circumference under bust, and hip circumference by 13cm (10.5%), 5.3cm (5.2%) and 12.1cm (9%) respectively.

Underestimating the high percentiles can lead to the same issues as overestimating the low percentiles: since the boundary users are thought to be closer to the average than they are, accommodation levels can be lower than intended. Therefore, similar to the low percentiles, the PeopleSize anthropometry estimates at the high percentiles display errors in the most detrimental direction (underestimation).

Finally, despite these differences, it is worth noting that PeopleSize offers estimates that are much closer to reality than values obtained from a standard normal distribution (Table 5). PeopleSize does not disclose how the percentiles are estimated, only mentioning the percentile values are “calculated from coefficients”. The simplest way to achieve this would be to use the mean and standard deviation of the distributions to estimates percentiles, but we know that would lead to extremely large errors at the extreme percentiles. The values provided by PeopleSize indicate that the estimation method very likely includes some modelling of skewness, although we cannot know for certain how this is achieved.

In summary:

- At the 50th percentile, PeopleSize provides reasonable estimates of anthropometric dimensions. Most estimates are of the same order of magnitude as Standard Errors of Measurement for anthropometry, and as errors due to the distribution fitting and reweighting process.

- At the 5th and 95th percentiles, PeopleSize estimates tend to be closer to the median than NHS data; i.e. the 5th percentile’s dimensions tend to be overestimated, and the 95th percentile’s tend to be underestimated. This is problematic since this can lead to a smaller accommodation range than intended.

Guidelines for Use of the Data

Estimates on the precision and accuracy

Sources of error in anthropometry and associated magnitudes

Errors due to the measurement procedure
Errors in anthropometry may be due to small absolute size, landmarks difficult to locate precisely, soft tissue deformation, and the inconsistency of the posture of the subject.
Kouchi et al.[19] assessed the intra-observer repeatability of measurements by performing 219 measurements on 12 subjects twice. They quantified the mean absolute difference (MAD) and technical error of measurement (TEM) for each dimension. They found that the relative errors (MAD and TEM) are larger for smaller measurements (< 10cm); however, the absolute errors do not generally depend on the size of the measurements themselves. This is likely because absolute errors are mostly caused by soft tissue deformation and inaccuracies in locating landmarks. Typical absolute errors are approximately:

- 1-2mm for small to medium (<100 cm) lengths and breadths measured from bone landmarks;
- 3-5mm for large (>150 cm) lengths and breadths (e.g. cervicale height, stature) or for lengths and breadths measured from "soft" landmarks (e.g. interscye);
- 5-10mm for circumferences (e.g. chest and waist circumference) and functional measures where subject position has a larger influence on the measurement (e.g. arm reach from back, elbow height sitting).

They state as a summary that "it seems that a measurement is unreliable when size is small, landmark is difficult to locate precisely, the subject must take a particular posture and the part measured is easily deformed".

In another study, Perini et al.[20] quantified the inter- and intra-operator TEM of skinfolds measurements. They found relative TEM values of approximately 5% for all 9 skin folds measured. Although the present project is not directly concerned with skin folds measurements, which are generally used to estimate body fat percentage, these results give some insight into the precision of anthropometric measurements not taken from bone landmarks.

Marks et al.[21] assessed the source of measurement error in a survey of 229 subjects. They found that measurements such as height, sitting height, and weight, were overall much more reliable (twice of more) than skinfolds or bitrochanteric breadth. For the latter, most of the TEM was

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[19] Kouchi, M., Mochimaru, M., Tsuzuki, K. and Yokoi, T., 1996. Random errors in anthropometry. *Journal of human ergology*, *25*(2), pp.155-166.

[20] Perini, T.A., Oliveira, G.L.D., Ornellas, J.D.S. and Oliveira, F.P.D., 2005. Technical error of measurement in anthropometry. *Revista Brasileira de Medicina do Esporte*, *11*, pp.81-85.

[21] Marks, G.C., Habicht, J.P. and Mueller, W.H., 1989. Reliability, dependability, and precision of anthropometric measurements. *Am J Epidemiol*, *130*(2), pp.578-587.

due to imprecision by the operator, rather than random error or fluctuations in the subjects' anthropometry.

More recently, Kouchi et al.[22] assessed the reliability of locating 35 landmarks, as well as that of the associated anthropometric measurements. They found inter-operator MAD in landmark locations were approximately 2-10mm, and interestingly, also found that the MAD for the anthropometric measures themselves were smaller than the landmarking errors.

Finally, Jamison et al.[23] analysed the measurement error for 15 facial dimensions measured on42 subjects by two operators. They report typical inter-operator errors of 1-7mm, depending on the measurement, which is line with values reported in other studies. Interestingly, they mention that inter-operator differences are magnified for multivariate comparisons, and as such, multivariate comparisons between individuals' anthropometry should never use raw data from multiple operators.

In summary, **measurement errors typically range from approximately 1 to 10mm**. Multiple factors can influence these values, including:

- The operator's experience level,
- the size of the measurement (larger measurements have larger absolute errors),
- the ease of locating the landmark (bony landmarks are typically easier to locate, although they can also be source of error if the landmark is an area rather than a point, e.g. acromion or greater trochanter),
- whether the measurement is on or across soft tissue, rather than bone (e.g. most circumferences),
- whether the measurement is sensitive to the subject's posture (e.g. elbow height sitting, reach).

Errors associated with the reweighting process

This project used a reweighting method to obtain estimates of detailed anthropometry from the measurements of height and weight. Since this is a statistical method, it is associated with errors that can be quantified by running the method on a dataset for which the detailed anthropometric dimensions are known.

We have performed such a reweighting of a dataset with known dimensions as part of our assessment of the method in Appendix 1. Using AWAS (Australian Warfighter Anthropometry Survey) as the detailed dataset, and CAESAR (Civilian American and European Surface Anthropometry Resource) as the reference dataset, we obtained **absolute errors of 5mm and 0.4kg** for stature and weight respectively, and mean relative errors of 0.26% and 0.34% **for the 95th percentile**. **For the 5th percentile**, relative errors were 0.30% and 0.97%, and **absolute errors 0.5mm and 0.6kg for stature and weight**, respectively.

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[22] Kouchi, M. and Mochimaru, M., 2011. Errors in landmarking and the evaluation of the accuracy of traditional and 3D anthropometry. *Applied ergonomics*, *42*(3), pp.518-527.
[23] Jamison, P.L. and Zegura, S.L., 1974. A univariate and multivariate examination of measurement error in anthropometry. *American Journal of Physical Anthropology*, *40*(2), pp.197-203.

Moreover, the study by Reddie and Parkinson[24] reports absolute and relative errors associated with the reweighting process. For the 1-NN approach – the one used in this project – the errors are largest at the extreme percentiles. Reddie reports maximum relative errors of 0.63%, 4.92% and 2.83% for stature, mass and BMI respectively. The largest error for stature occurred at the 1st percentile, while the largest errors for BMI and weight occurred at the 99th percentile. The corresponding **maximum absolute errors are 10mm in stature (1st percentile), 2.5 kg/m^2 in BMI (99th percentile), and 2.8kg in mass (99th percentile)**, respectively. The mean relative errors are 0.06%, 0.37% and 0.41%; the corresponding mean absolute errors are 1mm, 0.2 kg/m2, and 0.4kg for stature, BMI, and mass respectively, across all percentiles from 1st to 99th. It is worth noting that, in both our and Reddie's studies, the errors were very small inside the 5th-95th percentile range, and only increased to noticeable amounts for the 1st to 5th, and 95th to 99th percentiles. This is illustrated on *Figure 4*, reproduced from Reddie and Parkinson's study.

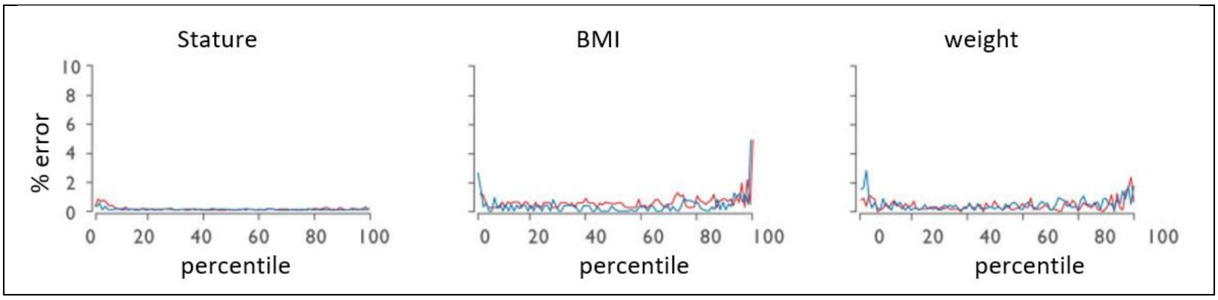

Figure 4 - relative errors from the reweighting method as a function of population percentile. From Reddie and Parkinson[25].

Findings were similar in our assessment of the reweighting method: for the 50th percentile, we found no difference between the reference and reweighted datasets (0mm and 0.0kg differences in stature and weight).

In summary, the errors associated with the reweighting process are negligible inside of the 5th-95th percentiles, compared to the measurement errors themselves. However, for percentiles smaller than the 5th or larger than the 95th, these errors increase rapidly in magnitude. At the 1st and 99th percentiles, the errors are roughly of the same order of magnitude as the measurement errors (e.g. approximately 10mm in stature, 2.8kg in weight).

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[24] Reddie, M. and Parkinson, M.B., 2022. A comparison of approaches to reweighting anthropometric data. *Ergonomics*, *65*(10), pp.1397-1409.

[25] Reddie, M. and Parkinson, M.B., 2022. A comparison of approaches to reweighting anthropometric data. *Ergonomics*, *65*(10), pp.1397-1409.

Guidelines for use of anthropometry data

The following section presents some general considerations, guidelines and caveats pertaining to the use of anthropometry data in design.

The role of anthropometry in Human-Centred Design

Human-Centred Design (HCD) is an approach to design that focuses on the users, with the aim to improve accessibility and usability of systems and environments. Specific to the transport Industry, HCD can potentially be applied, but is not limited, to the following areas:

- Passenger spaces in trains, tramways, buses;
- Driver cabin interiors;
- Transport-related public spaces (e.g. bus and tramway stops);
- Maintenance tasks on trains, tramways and buses;
- Office spaces.

Anthropometry plays a role in all of the above areas; however, each of these also have their specificities related to the design and assessment process. For instance, design and assessment of passenger spaces may require consideration of multiple individuals occupying the same space, while assessing accessibility of equipment for maintenance purposes may requires considerations of field of view and strength requirements.

Anthropometry is one essential part of the Human-Centred Design process, and is usually used to assess space requirements against specific dimensions of a design. However, the overall HCD process must be kept in mind (**Error! Reference source not found.**):

- Physical space requirements are one part of HCD. Other parts include noise, lighting, vibration, tactile feedback, temperature, vision.
- Anthropometry is one of the factors influencing space requirements. Other factors include safety, line-of-sight requirements, comfort, strength requirements.

As such, anthropometry can be seen as one set of tools within the “Human-Centred Design” toolbox. Alternatively, satisfying users’ space requirements can be seen as a necessary, but not sufficient, condition for the acceptability of a given design.

From design parameters to anthropometry: a framework

When considering potential designs for a specific environment, one needs to relate critical design dimensions to their associated anthropometric dimensions in order to assess accommodation levels. This process, depending on the environment and tasks considered, can be highly complex.

In this section, we propose a general framework for identifying critical dimensions associated with a particular design.

1. Identify which tasks need to be performed within the environment

The first step toward identifying critical dimensions is to break down its function into a list of individual tasks that need to be performed within the environment (*task analysis*). Some examples:

- When considering a seating layout in a tramway carriage:
  - Users must be able to access the seating space;
  - Users need to be able to sit safely and comfortably,
  - Users need to be able to exit the seating space…

- When considering the layout of a driver's cabin:
  - The driver must be able to enter and exit the cabin safely and comfortably,
  - The driver needs safe and comfortable seating,
  - The driver needs controls that are easy to identify and operate…

2. Identify the criticality, frequency and risks associated with each task

After each task has been identified in the step above, it is important to assess their criticality, the expected frequency at which each task will be performed, and the risks associated with not being able to carry the task. The more critical, more frequent, and/or higher risk the task is, the most attention should be paid to the corresponding design element, and a higher accommodation level should be sought.

If a task is performed very frequently, the designer should aim to accommodate as many users as possible (see section below for discussion on accommodation levels). One goal should also be to make the task as effortless (or *comfortable*) as possible. However, designing for accommodation levels (e.g., 99% of users need to be able to perform the task) is a different issue from designing for *comfort*. Assessing whether a task is doable for a specific user can often be reasonably broken down into individual physical components and assessed objectively. On the other hand, comfort is related not only to physical characteristics, but also to psychological and perception considerations. A significant part of human factors and ergonomics professionals make the argument that discomfort and comfort are not two ends of the same scale, and that the absence of discomfort is a necessary, but not sufficient, condition to achieve comfort[26,27].

A task that is infrequent, but highly critical, also needs a high level of consideration in the design of the relevant elements. Using an emergency stop control may be such an example. The high risks associated with failure to perform the task warrant its design to accommodate the large majority of users.

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[26] De Looze, M.P., Kuijt-Evers, L.F. and Van Dieen, J.A.A.P., 2003. Sitting comfort and discomfort and the relationships with objective measures. *Ergonomics*, *46*(10), pp.985-997.

[27] Vink, P. and Hallbeck, S., 2012. Comfort and discomfort studies demonstrate the need for a new model. *Applied ergonomics*, *43*(2), pp.271-276.

3. Define the target accommodation level

Based on the two previous steps, a target accommodation level can be defined. Accommodation level here refers to the percentage of users that are expected to be accommodated by the design, i.e. able to perform a specific task given a specific design. As mentioned above, the more frequent, critical, and/or the more risks are associated with the task, the larger the accommodation level should be.

Common targets for accommodation are:[28]

- Majority accommodation, which refers to accommodating 95% of the target users. Please note that 95% of users does not always mean the central 95% of the population anthropometry-wise. See section below for more detail.
- Full accommodation, which usually translates to accommodating 98% of the population. This level is recommended for safety critical design aspects and where failure to accommodate could result in hazardous conditions.

A broader accommodation range usually means more difficulty for the designers and can also result in cost increases. In many cases, accommodation ranges are a compromise between multiple tasks and scenarios: in an environment with a fixed amount of total space available, it is usually not possible to maximise the space dedicated to every element.

4. Identify the boundary users

Once a desired accommodation level has been set, the designer must identify which users constitute the boundaries of the user base to be accommodated. If for instance, a 95% accommodation level is desired, the designer can elect to accommodate down to the 5th percentile user (and assuming that all other users above the 5th percentile will also be accommodated), or up to the 95th percentile user (and other users below the 95th percentile will also be accommodated), or the central 95% of users. In general, there are four ways of selecting the boundary users:[29]

- *Design for the smallest*. In this case, the boundary user is in the low percentiles of the population range (e.g. 5th percentile for a 95% accommodation level), and if this user can perform the task, the assumption is that other users above this percentile will also be able to perform the task. This principle can be applied to tasks requiring reach or the use of physical force.
- *Design for the largest*. This is the opposite approach to the above; the boundary user is in the high percentiles of the population range (95th percentile for 95% accommodation level). This applies primarily to clearances, access, and overhead clearances.

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[28] Hudson, J.A., Zehner, G.F. and Meindl, R.S., 1998, October. The USAF multivariate accommodation method. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 42, No. 10, pp. 722-726). Sage CA: Los Angeles, CA: SAGE Publications.

[29] National Aeronautics and Space Administration (2010). Human Integration Design Handbook.

- *Design for the average*. This principle can apply to elements in design that are not adjustable (e.g. fixed height seating, toilets). This principle should be seen as an acceptable compromise rather than optimal HCD practice.
- *Design for a range*. This principle can be applied to determine the amount of adjustability that should be built into such things as variable height work surfaces and adjustable seating.

Note that in all cases, the anticipated male/female split in the target population should be considered. For instance, if the target population has an even split of males and females, accommodating a range of 5th percentile female – 95th percentile male will result in an overall 95% accommodation level for the population (females below the 5th percentiles and males above the 95th percentile won't be accommodated).

Also note that identifying the boundary users requires careful consideration of the task and population. In some cases, the design will need to accommodate specific users with particular needs and/or constraints. For instance, wheelchair access considerations may be the primary design driver for tramway egress, as well as for some reach-related tasks. In those cases, these users will set the boundary case for design assessment, rather than specific anthropometry percentiles.

5. Identify the critical anthropometric dimensions

Once the boundary users have been identified, the next step consists in identifying the critical design dimensions affecting the accommodation level, and the associated anthropometric dimensions. This requires assessment of the body posture during performance of the task, as well as mobility and flexibility requirements.

Once the critical anthropometric dimensions have been identified, the designer can select the corresponding values of these dimensions for the boundary users selected in Step 4. Design dimensions can then be compared against these anthropometric dimensions to assess design suitability.

Note that, in addition to the raw anthropometric dimensions, the designer must consider additional allowances to account for:

- Obstacles, projections, and safety considerations;
- Clothing. Additional allowances to account for clothing are presented in the relevant section of the present report.
- Change in population anthropometry over time, i.e. secular trends. If the design is expected to be in use for several years, secular trends in population anthropometry must be considered to ensure the design will be suitable for its entire life cycle. Estimates of secular trends are presented in the relevant part of the present report.

Additionally, special consideration must be given when multiple anthropometric dimensions are used together, and when multiple users are sharing the same space.

The multivariate case

In some cases, multiple anthropometric dimensions must be considered simultaneously. For instance, “buttock-to-knee length” and “sitting hip breadth” should be considered to assess seat dimensions. As more dimensions need to be considered, the design constraints become more restrictive. However, it would be an error to use the same target percentile dimensions simultaneously, because an individual with a 95th percentile value on one dimension will usually not have a 95th percentile value on the other. Using both 95th percentile values at the same time will result in design constraints that are too restrictive.

One common approach is the use of *boundary manikins*, which represent individuals at the edges of the overall population, with respect to a combination of anthropometric dimensions, however, the present project only provides univariate data, and we were unable to generate boundary manikins for the Australian population because of data access limitations.

Without access to boundary manikins, one approach consists in selecting combinations of dimensions that form the worst-case scenario, which is the approach suggested by NASA in their HSI handbook[30]:

“*It should also be noted that the worst-case scenario often depends on a combination of body dimensions. For example, a person with short arms but a long buttock-knee length may hit their knees on the dashboard of their car when they adjust their seat close enough to reach the steering wheel*”.

One final practical note: it is incorrect to directly add two dimensions of a certain percentile together. For instance, the sum of 95th percentile upper arm and forearm lengths will not equal the 95th percentile arm length (the sum will be larger).

Multiple users

When multiple users are occupying the same space, consideration must be given to the likelihood of several users at the extremes of the population’s anthropometry occupying the space together, e.g. two 95th percentile shoulder breadth males sitting next to each other.

In those cases, considering multiple users with body size percentiles corresponding to the target accommodation range will be too restrictive. For instance, if targeting 95% accommodation for seat spacing, considering two 95th percentile shoulder breadth males is too restrictive. There is only a 0.25% chance of this scenario occurring (5% x 5%) which would correspond to a 99.75% accommodation range (and to design dimensions larger than necessary for the intended 95% accommodation).

Two approaches are possible in these cases:

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[30] National Aeronautics and Space Administration (2010). Human Integration Design Handbook, p.52.

1. Use the anthropometry percentiles that corresponds to a x% likelihood of individuals occupying the space. In the previous example, a reasonable approach would be to consider two 75th percentile males (a 6% chance of occurrence).
2. Use percentile dimensions for one user and check which percentile can be accommodated at most by the other user(s). This is the approach mentioned in the NASA Human Integration Design handbook[31] (page 52). In the hypothetical scenario above, it could be that only a 20th percentile male can fit next to a 95th percentile male. It is then up to the designer to assess whether this is acceptable.

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[31] NASA Human Integration Design Handbook.

Secular Trends, Ethnicity, and Clothing

Introduction

The previous section provided detailed anthropometric data for Australian adults aged 18-64, as well as some guides for applying anthropometry. In the context of anthropometry applied to Human Factors, additional factors must be considered, including secular trends, ethnicity, and clothing.

Secular trends refer to long-term changes over time [1]. Considering secular trends in design allows for the accommodation of changing body dimensions and sizes over decades [2, 3]. This is especially important in situations where equipment and vehicles are intended to be used for the next 10 to 20 years, to ensure optimal comfort, safety, and accessibility to users. In contrast, failure to account for secular trends may result in vehicles that are ill-fitted, uncomfortable, or even unsafe. The first part of this section examines secular trends in both developed and developing countries, providing insight into how anthropometric dimensions have changed over the past 150 years, and how they are likely to change in the future.

When designing vehicles and equipment for population use, it is also necessary to consider the influence of ethnicity on the variance in body dimensions within that population. Anthropometric data, such as height and weight, can differ across ethnic groups due to genetic and environmental factors. This is especially true for multicultural communities across Australia. However, large data sets used to inform equipment and vehicle design do not often include data on ethnicity and may be limited in their representativeness. The second part of this section examines the variance that exists within populations according to ethnicity and provide guidelines on how dimensions are likely to vary across ethnic groups.

Finally, the anthropometric data provided in this report is based on semi-nude measurements, i.e. in underwear but without clothes or shoes. While this is necessary to capture true size, it provides dimensions that are not reflective of contexts where clothes and shoes are worn, such as working and travelling on passenger vehicles. This means that vehicles and equipment designed using raw anthropometric data without adjustment for clothing and equipment may be restrictive or unusable. For this reason, personal equipment and clothing correction factors are applied to anthropometric data to account for dimensions added by equipment and clothing. The final part of this section reviews and summarises anthropometric design literature for clothing correction factors, emphasising the need to account for these factors in prediction models.

Secular trends in anthropometry

Secular trends refer to gradual, persistent, long-term changes over time – across decades, generations, or centuries. Since the mid-19th century, there have been observable secular trends in height and weight, largely attributed to changes in standards of living, nutrition, and healthcare [1]. These trends are most evident in developed countries but are also emerging in developing countries.

Height

Section Summary

The most current data for Australia indicate increases per decade between 0.5cm and 1.cm. However, also note that in developed countries, including Australia, secular trends in height have begun to slow. This has been observed in both children and adult populations. Recent figures are indicative of a plateau and even regressions (see the Netherlands and the US).

Secular trends have been observed for height in developed and developing countries at different rates. Up to 80% of height variance is believed to be due to genetic factors, with the remaining 20% dependent on environmental influence, in particular, access to nutrition and exposure to disease [4].

Table 10 below summarises the total increases in height, as well as average increase per decade across developed and developing countries.

Developed countries

From the mid-1800s, a steady increasing trend has been observed for height in developed countries. However, since the 1970s-1980s [5], the rate of this increase has slowed. It has been suggested that the plateau observed in developed countries may be the result of new environmental stress factors in childhood or adolescence, or the decreasing nutritional quality of food. Alternatively, the genetic potential for height may have been realised [5].

Children and adolescents

An analysis of 1099 Turkish primary school children aged between 7 and 15 revealed significant increases in height between 1993 and 2016 for both boys and girls (0.1 to

0.8cm/decade). However, between 2003 and 2016, the change in height plateaued for most age groups [6].

In Canada, a study comparing differences of 4,500 students between 1972 and 2017 revealed significant differences in height, ranging from 1.4cm (11yo) to 3.2cm (14yo) in boys, and from 1.4cm (8yo) to 3.6cm (11yo) in girls [7]. Notably, once male children reached the age of 16, differences in body height were no longer significant between the 1972 and 2017 cohorts. However, in females, the difference in height remained up until the age of 17 (2cm).

The Netherlands, known for having the tallest population in the world, has reported increases in height since 1858, with an overall height gain of 21cm over 140 years [8]. However, since 1980 the trend has slowed [8], and no significant difference was observed between in Dutch children born in 1997 and those born in 2009 [9].

Adults

In Poland, secular trends in height were analysed using data from six national surveys of 19-year-old male conscripts conducted across 1965, 1976, 1986, 1995, 2001, and 2010 [13]. Over this 45-year time-period, mean height increased by 7.8cm, from 170.5 cm in 1965 to 178.3 in 2010 (~1.7cm per decade). However, the rate of increase declined from 2.4cm per decade between 1965 and 1976 to 0.8cm per decade between 1995 and 2001. Interestingly, the final time-period from 2001 – 2010 saw a slight increase to 1cm per decade.

In Turkey, historical data were utilised to compare height from 1886 to 2006 in men, and from 1937 to 2006 in women [17]. Male height increased by 11.9cm over 120 years (1cm/decade), while female height increased by 6.6cm over 69 years (1cm/decade). Notably, the secular trend in height was not entirely linear, with decreases in male height observed in the 1930s, aligning with World War I and the Independence War (1918 – 1923), followed by a gradual increase. Results from the 1950s and 1960s show an additional decrease in height for both males and females, corresponding with births during World War II and the post-war depression. Since the 1970s, height has continued to increase, with a difference of 2.1cm in males between 1999 and 2006, and 1.9cm in females between 1997 and 2006. However, a recent analysis of secular changes in Turkish primary school children (discussed above) suggest the trend in height may be slowing once again.

Plateaus in adult height have also been reported in northern Europe [14, 15]. In Norway, conscript data from 1878 to 2010 revealed an increase of 10.9cm (0.8cm/decade), with the largest increase between 1936 and 1956 (1.6cm/decade) [15]. However, between 1976 and 1996, average height increased by 0.3cm, and no significant difference was detected between 1996 and 2010. Reflecting trends in Dutch children, recent data from 2020 in the Netherlands indicate that Dutch men and women born in 2001 were 1cm and 1.4cm shorter respectively than those born in 1980 [14].

A similar trend has been reported in the United States. Despite being one of the tallest nations at the beginning of the 20th century, and experiencing growth rates of 1cm/decade up until the 1950s, increases in stature have stalled and even declined [4]. A recent report on the trends of >46,000 American adults found that, between 1999 and 2016, the average height of adult males decreased significantly from 175.6cm to 175.4cm [16].

In Australia, data collected between 1896 and 1996 show an increase in height, from 169cm to 179cm in men, and from 155.5cm to 165.9cm in women (1cm/decade) [10]. As seen in other developed countries, the largest increases were observed in the early 20th century, between 1896 and 1936, after which increases in height began to decline. In the final decade, between 1986 and 1996, the increase in height had reduced to 0.1cm/decade in men and 0.5cm/decade in women.

Comparisons of Royal Australian Navy (RAN) personnel matched by age and occupation revealed a difference of 4.7cm between 1977 and 2015 (1.2cm/decade) [12]. This increase is markedly higher than what has been observed in wider population data and may be explained by sample characteristics. Firstly, the total sample size of 1,186 is smaller than that of other studies and may be limited in its ability to capture variability. Secondly, the sample is highly specific and limited to military personnel who met RAN eligibility requirements (including minimum height requirements). Interestingly, a similar comparison of body dimensions in Royal Australian Airforce Crew revealed less extreme secular changes, more closely resembling those of the wider population. Between 1971 and 2005, the height of age and position matched personnel increased by 2.6cm (0.78cm/decade) [11].

	Sample size	Age range	Time period	Absolute change	Change per decade
Developed countries					
	Children and adolescents				
Canada[7]	9,473	6 – 17.9	1982 – 2017	1.8cm	0.5cm
Netherlands[8]	128,186	0 – 20	1955 – 1997	8cm (boys); 7.7cm (girls)	1.9cm (boys); 1.8cm (girls)
Netherlands[9]	12,005	0 – 21	1997 – 2009	0.8cm (boys); 0.1cm (girls)	Nil
Turkey[6]	3,180	7 – 15	1999 - 2016	1.1 – 8.3cm (boys); 1.3 – 7.2cm (girls)	0.1 – 0.8cm (boys); 0.1 – 0.7cm (girls)
	Adults				
Australia[10]	-	18+	1986 – 1996	10.3cm	1.0cm
Australia[11]	440	17 – 56	1971 – 2005	2.6cm	0.78cm
Australia[12]	1,186	18 – 40	1977 – 2015	4.7cm	1.4cm
Poland[13]	146,935	19	1965 – 2010	1.8cm	1.7cm
Netherlands[14]	719,000	19 – 60	1980 – 2001	-1.0cm (men); -1.4cm (women)	-0.5cm (men); -0.7cm (women)
Norway[15]	-	-	1878 – 2010	10.9cm	0.8cm
United States[16]	46,481	20+	1999 – 2016	-0.2cm	Nil
Turkey[17]	74,200	18 – 59	1884 – 2006 (men); 1937 – 2006 (wom.)	11.9cm (men); 6.6cm (women)	1cm (men); 1cm (women)

Developing countries					
	Children and adolescents				
India[18]	17,953	0 – 18	1975 – 2013	3.1cm (boys); 1.0cm (girls)	0.9cm (boys); 0.3cm (girls)
Seychelles[19]	14,973	5 – 15	1956 – 2006	10cm (boys); 13cm (girls)	2cm (boys); 2.6cm (girls)
	Adults				
Chile[2]	6,711	17 - 76	1995 – 2016	2.2cm (men); 4.4cm (women)	1.1cm (men); 2cm (women)
Indonesia[20]	30,656	20 – 40	1953 – 1995	4.6cm (men); 3.4cm (women)	1.3cm (men); 0.9cm (women)
Mexico[21]	675	6 – 29	1978 – 2000	2.7cm (men); 1.6cm (women)	1.3cm (men); 0.7cm (women)

Table 10 - Absolute change and change per decade in height across developed and developing countries. Sample size is the total of all cohorts.

Developing countries

In developing countries, trends in stature vary according to socioeconomic opportunity and access to resources.

Children

In rural India, child and adolescent height from birth to 18 years was observed to increase at rates similar to children of developed countries. The overall increase in height for boys was 3.1cm (0.9cm/decade), and 1.0cm for girls (0.3cm/decade). The authors infer that India has reached a similar growth potential to that of developed countries. However, it is also possible that the limited growth observed over this time frame is due to barriers in accessing nutrition and healthcare in rural India, with evidence of a high prevalence of stunted growth in Indian children [18, 22, 23].

In the Seychelles, the height of children aged 5 to 15 years was compared between 1956 and 2006 [19]. Over the span of 50 years, the height of boys increased by 10cm (2cm/decade), while the height of girls increased by 13cm (2.6cm/decade). Comparisons between 1956 and 1999, and between 1999 and 2006 also indicate that the secular trend in height is slowing for boys, from 1.62cm to 1.14cm per decade, but increasing for girls, from 0.93cm to 1.82cm per decade.

Adults

In Java, Indonesia, adult height was observed to increase by 4.6cm for men and 3.4cm for women between 1953 and 1995, with an average increase of 1.3cm and 0.9cm per decade for men and women respectively [20]. While these values are similar to those observed in developed countries, the rate of increase has remained steady for men, and has been increasing for women. In men, between 1955 and 1965, height increased by 1.2cm and by 1.1cm between 1985 and 1995. By contrast, in women, height increased by 0.4cm between 1955 and 1965, and by 1.4cm between 1985 and 1995. The authors propose that the notable difference between sexes is likely due to gender inequalities in education and income in earlier decades, which are beginning to narrow.

Similar patterns have been observed in South America. In a rural population in southern Mexico, height increased by 2.7cm (1.3cm/decade) for men and 1.6cm (0.7cm/decade) for women between 1978 and 2000 [21]. These trends reflect changes in conditions in Mexico, including limited access to healthcare, portable water, and sanitary facilities up until the 1970s, and economic collapse in the 1980s, affecting household income, nutritional status, and health. Subsequent growth in this rural population may be attributed to increased access to healthcare, education, and varied diets [21].

Weight

Section Summary

Secular trends indicate a continuing increase in weight in most developed and developing countries. In developed countries, including Australia, the rate of increase is between 1.5 and 3.3kg per decade.

Secular trends are also evident in weight measurements in children and adults across the world. Secular increases in weight are the result of increases in body size and body shape, corresponding to increased height and increased adiposity [1]. Table 11 below summarises the total increases in weight, as well as average increase per decade across developed and developing countries.

Developed countries

In developed countries, increases in body weight and increasing rates of obesity have been observed since the 1960s for adults and the 1980s for children [1].

Children and adolescents

In Canada, data collected in 1982 and 2017 revealed significant increases in body mass in girls from the age of 10 (2.3kg) and boys from the age of 11 (1.9kg). By the age of 17, the difference in body mass reached 6.5kg in males and 7.4kg in females. Interestingly, the prevalence of overweight and obesity appeared to stabilise at 21% around 2004 [7].

In Turkey, significant increases in weight were observed in children aged 7 to 15 years, with an average change per decade between 4.5kg to 9.5kg in boys, and between 3.8kg and 7.9kg in girls. Unlike the slowing trend observed in height in this sample, weight increases continued consistently across the measurement periods [6].

Adults

In Poland, average body weight increased from 63.2 kg in 1965 to 73.1 in 2010, with the highest gain between 2001 and 2010 (3kg) [13]. In Turkey, average body weight increased from 62kg to 77.8kg in men, and from 52.9kg to 67kg in women between 1937 and 2006 [17]. As in Poland, the largest increase was observed in the most recent decade (4.6kg in men and 3.2kg in women), corresponding with increasing rates of overweight and obesity between 1990 and 2000. In the US, linear increases in body weight have been observed between 1999 and 2016 [16]. In men, average weight increased from 85.9kg to 89.8kg (2.3kg/decade), and in women average weight increased from 74.3kg to 77.4kg (1.8kg).

	Sample size	Age range	Time period	Absolute change	Change per decade
Developed countries					
	Children and adolescents				
Canada[7]	9,473	6 – 17.9	1982 – 2017	7.0kg	2.0kg
Turkey[6]	3,180	7 – 15	1999 - 2016	7.7 – 16.2kg (boys) 6.5 – 13.4kg (girls)	4.5 – 9.5kg (boys) 3.8 – 7.9kg (girls)
	Adults				
Australia[11]	440	17 – 56	1971 – 2005	5.0kg	1.48kg
Australia[12]	1,186	18 – 40	1977 – 2015	12.4kg	3.3kg
Poland[13]	146,935	19	1965 – 2010	9.9kg	2.2kg
Turkey[17]	74,200	18 – 59	1937 – 2006	15.8kg (men); 14.1kg (women)	2.3kg (men); 2.kg (women)
United States[16]	46,481	20+	1999 – 2016	3.9kg (men); 3.1kg (women)	2.3kg (men); 1.8kg (women)
Great Britain[24] - **BMI**	19,406	43 – 47	1990 – 2018	2.7kg/m^2 (men); 2.8 kg/m^2 (women)	1.0kg/m^2

Developing countries					
	Children and adolescents				
Seychelles[19]	14,973	5 – 15	1956 – 1999	15kg (boys); 9kg (girls)	3kg (boys); 1.8kg (girls)
	Adults				
Chile[2]	6,711	17 - 76	1995 – 2016	12.1kg (men); 6.2kg (women)	5.8kg (men); 3kg (women)
Chile[2] - **BMI**	6,711	17 - 76	2016 – 1995	3.5 kg/m^2 (men); 1.1kg/m^2 (women)	1.7kg/m^2 (men); 0.5kg/m^2 (women)

Table 11 - Absolute change and change per decade in weight and BMI across developed and developing countries. Sample size is the total of all cohorts.

Developing countries

As with height, increases in body weight have been observed in developing countries more recently, most likely due to improvements in healthcare, nutrition, and quality of life.

Children and adolescents

In children and adolescents in the Seychelles, increases in weight were observed between 1956 and 1999 [19]. Compared to 1956, boys aged 15 years were 15kg heavier (3kg/decade), while girls aged 15 years were 9kg heavier (1.8kg/decade). Notably, it was reported that the relative increase in weight was five times higher than the relative increase in height over the same time period.

Adults

In Chilean adults, significant increases in weight have been observed between 1995 and 2016, a difference of 6.2kg for women (3kg/decade) and 12.1 kg for men (5.8kg/decade) [2].

Other measures

Section Summary

Secular trends in other body dimensions appear to reflect and be driven by secular trends in height and weight, with increases in measures of length and breadth.

Secular changes in other body dimensions have been reported inconsistently and are summarised in Table 12 below.

	Sample size	Age range	Time period	Absolute change	Change per decade
Bideltoid breadth					
Australia[12]	1,186	18 – 40	1977 – 2015	3.1cm	0.8cm
Buttock-knee length					
Australia[11]	440	17 – 56	1971 – 2005	0.8cm	0.2cm
Australia[12]	1,186	18 – 40	1977 – 2015	2.1cm	0.6cm
Chile[2]	6,711	17 - 76	1995 – 2016	1.5cm (men); 1.3cm (women)	0.7cm (men); 0.6cm (women)
Hip breadth sitting					
Australia[12]	1,186	18 – 40	1977 – 2015	2.6cm	0.68cm
Chile[2]	6,711	17 - 76	1995 – 2016		
Hip circumference					
Australia[11]	440	17 – 56	1971 – 2005	1.3cm	0.4cm

Leg length					
Mexico[21]	675	6 – 29	1978 – 2000	1.9cm (men); 1cm (women)	0.9cm (men); 0.5cm (women)
Shoulder breadth					
Chile[2]	6,711	-	1995 – 2016	6.1cm (men); 4.2cm (women)	2.9cm (men); 2cm (women)
Sitting height					
Australia[11]	440	17 – 56	1971 – 2005	1.1cm	0.3cm
Australia[12]	1,186	18 – 40	1977 – 2015	2.7cm	0.7cm
Chile[2]	6,711	17 - 76	1995 – 2016	1.5cm (men); 1.4cm (women)	0.7cm
Mexico[21]	675	6 – 29	1978 – 2000	0.8cm (men); 0.6cm (women)	0.4cm (men); 0.3cm (women)
Thigh clearance					
Australia[12]	1,186	18 – 40	1977 - 2015	1cm	0.3cm
Chile[2]	6,711	17 - 76	1995 – 2016	2.5cm (men); 0.2cm (women)	1.2cm (men); 0.1cm (women)
Waist circumference					
Great Britain[24]	19,406	43 – 47	1990 – 2018	8.1cm (men); 12.2cm (women)	2.9cm (men); 4.4cm (women)
United States[16]	46,481	20+	1999 – 2016	3cm (men); 5.8cm (women)	1.8cm (men); 3.4cm (women)

Table 12 - Absolute change and change per decade in other body dimensions across developed and developing countries. Sample size is the total of all cohorts.

Section summary

Height stagnation in the Netherlands indicates a slowing and reversal of the previously increasing trend. It has been suggested that the decrease observed in the Netherlands may be due to an increase in immigration from shorter population groups and their children. However, height also stalled in sub-populations with both parents, and all four grandparents, born in the Netherlands [14]. Other possible explanations include changes in nutrition and socioeconomic events, such as the 2007 financial crisis. Similarities between the Netherlands, the US, and Australia could be explained by an increase in processed food intake, and a subsequent decrease in nutrient intake. This is reflected by the increasing trend in weight and obesity observed in Western countries. Recent socioeconomic events, including the far-reaching impact of the COVID-19 pandemic and the rising cost of living, may have further implications for future generations. Predictive factors of secular trends in body dimensions are complex and manifold and may not be evident until after trends are observed, However, it is recommended that design projects include secular trend allowances in their design, especially where the design process or lifespan of the vehicle spans a decade or more [12].

Overall, a likely scenario for Australia over the next 20 years is: no increase in stature, and a 2 to 3kg increase in weight per decade. A conservative scenario, which would lead to more accommodating designs, is an increase in stature of 10mm per decade, and an increase in weight of 3kg per decade.

Ethnicity and anthropometry

Body dimensions can vary within a population due to the influence of race and/or ethnicity. Ethnicity plays a crucial role in shaping physical characteristics, such as height, weight, and body composition. These differences may be due to genetic or environmental factors. One approach to inclusive design may be to consider population anthropometric measurements for each ethnic group's country of origin. For example, knowing there is a large community of Chinese Australians in Sydney, designers could consider the average height and weight of the general population in China. However, there is evidence to suggest that anthropometric measurements from a country of origin are not reflective of the anthropometric measurements of migrants and migrant families who have lived in another country for years or generations [25]. For this reason, we have focused on studies comparing anthropometric measurements across different ethnic groups (referred to as sub samples) living within the same geographical region or country.

NHS sample characteristics

The ABS reports sampling strategy and sample characteristics on the NHS webpage[32]. One major advantage of the NHS survey, compared to other anthropometric surveys, is the fact that the sample produced is representative of the Australian population as a whole, including location, sex, age and ethnicity. However, since we were not able to separate anthropometric data per ethnicity, it is of interest to examine whether different ethnicities within the same country have significant differences in anthropometry.

Height

Section Summary

Height variations exist within populations according to ethnicity. In Australia, the most notable variations exist between White and Asian populations (~9cm). Inconsistent differences have been reported when comparing European Australian and Aboriginal Australian sub samples. Differences between European and Pacific Islander subgroups have been reported in New Zealand, ranging from 2.7 to 4cm.

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[32] https://www.abs.gov.au/methodologies/national-health-survey-first-results-methodology/2017-18

Within sample differences in height according to ethnic sub samples are presented in Table 13.

As part of the Civilian American and European Surface Anthropometry Resource (CAESAR) project, anthropometric measurements were reported for the United States of America, the Netherlands, and Italy [26]. In the United States, differences in height were observed between Black and White populations. White females aged 18 to 29 and 45 to 65 years were significantly taller than Black females in the same age group (mean difference: 2.3cm and 2.5cm respectively). No significant difference was detected between Black and White females aged 30 to 44 years. In males, no significant differences were detected between Black and White participants aged 18 to 29 years. However, White males aged 30 to 44 years were 3.4cm taller than Black males, and White males aged 45 to 65 years were 3.3cm taller than Black males. Less pronounced differences were reported more recently by the U.S. Department of Health and Human Services: White males aged 20 years and older were 1.9cm taller than Black males, and White females were 0.7cm taller than Black females [16]. Interestingly, a study investigating the interaction between ethnicity, anthropometry and diabetes risk reported no difference in height between Black and White participants aged 45 to 84 years [27].

In the United States, differences in height have also been observed between Hispanic and non-Hispanic sub samples. Hispanic males and females are consistently shorter than non-Hispanic Black and White sub samples (mean difference: 6cm – 7.9cm) [16, 27]

Notable differences have been observed between White and Asian sub samples across the US, the UK and Australia. In the United States, significant differences were detected between White and Chinese participants, with differences of 7.7cm to 8.0cm observed for men, and 6.0 to 7.1cm observed for women [16, 27]. In Australia, a significant difference (9.4cm) was detected between Caucasian and Japanese men aged 18 to 40 years [28]. In Scotland, migrant and British-born South Asian and Italian women were compared with British women from the "general population" [25]. The greatest differences in height were between British women and British-born South Asian women (mean difference: 4.6cm) and between British-born Italian and British-born South Asian women (mean difference: 4.5cm). Differences have also been observed between European and Indian sub samples in New Zealand, where men of European descent were 10cm taller than their Indian counterparts, while women were 7.4cm taller [29].

In New Zealand, differences in height have also been observed between adults of European and Pacific Island descent. In a 1999 study of rural and urban New Zealanders, participants who identified as Māori and Samoan were significantly shorter than those who identified as European [30]. Specifically, Māori and Samoan men were 3cm and 4cm shorter than European men respectively, while both Māori and Samoan women were 4cm shorter than European women. Similar trends were exhibited 10 years later, with significant differences observed between European, Māori, and Pacific Islander groups [29]. Māori adults were 2.7-2.8cm shorter than their European counterparts, while Pacific Islanders were 3.1-3.3cm shorter.

Inconsistent patterns have emerged when examining height in European and Aboriginal Australians. In a comparison of Aboriginal Australians from remote communities in central and north-eastern Australia and European Australians from inner Melbourne, European Australian men were observed to be 6.7cm taller than Aboriginal Australian men, and European Australian women 5.6cm taller than their counterparts [31]. However, a comparison of Aboriginal Australians living across three remote communities in the Northern Territory with the general Australian population found that Aboriginal Australian females were significantly taller than women from the general population (mean difference: 1.1cm), while Aboriginal Australian males were only 1.4cm shorter than men from the general population. It is likely that the differences between these studies are driven, at least in part, by the differences between and within remote Aboriginal communities. Further, the sample size of the general population examined in [32] was nation-wide, and considerably larger (10,434 vs 220), increasing the potential to capture more variance in the general population.

Country	Sample size	Age range	Sub samples	*n*	Height (cm)
Australia[31]	397	18 – 35	European	220	178.8cm (men); 165.8cm (women)
			Aboriginal Australian	177	172.1 cm (men); 160.2cm (women)
Australia[32]	11,248	18+	General Population	10,434	176.1cm (men); 162.6cm (women)
			Aboriginal Australian	814	174.7cm (men); 163.7cm (women)
Australia[28]	284	18 – 40	Caucasian	140	180.9cm
			Japanese	144	171.5cm
New Zealand[30]	615	20 – 70	European	241	177.0cm (men); 165.0 cm (women)
			Māori	189	174.0cm (men); 161.0cm (women)
			Samoan	185	173.0cm (men); 161.0cm (women)
New Zealand[29]	933	17 – 80	European	313	176.9cm (men); 164.2cm (women)
			Māori	199	174.2cm (men); 161.4cm (women)
			Pacific Islander	200	173.8cm (men); 160.9cm (women)
			Asian Indian	224	169.6cm (men); 156.8cm (women)
Scotland[25]	259	20 – 42	British	50	160.4cm

			Migrant South Asian	63	157.0cm
			British-born South Asian	56	155.8cm
			Migrant Italian	39	158.8cm
			British-born Italian	51	160.3cm
United States[26]	2,082	18 – 65	White	1,819	178.7cm (men); 164.9cm (women)
			Black	263	176.9cm (men); 163.2cm (women)
United States[27]	6,814	45 – 84	White	2,360	176cm (men); 162cm (women)
			Chinese	646	168cm (men); 156cm (women)
			Black	1,442	176cm (men); 162cm (women)
			Hispanic	1,155	169cm (men); 156cm (women)
United States[16]	5,232	20+	Non-Hispanic White	1,777	177.4cm (men); 163.3cm (women)
			Non-Hispanic Black	1,144	175.5cm (men); 162.6cm (women)
			Non-Hispanic Asian	649	169.7cm (men); 156.2cm (women)
			Hispanic	1,662	169.5cm (men); 156.7cm

Table 13 - Differences in height according to ethnicity within the same country.

Weight

Section Summary

As with height, weight variations exist within populations according to ethnicity. Most relevant to Australia are differences that exist across European, Asian, Pacific Islander, and Aboriginal Australian community groups. Comparisons between White and East Asian sub samples indicate that White adults are heavier, with differences ranging from 13.9kg to 18.6kg. Comparisons of White and South Asian sub samples suggest White men are up to 5.5kg heavier than South Asian men, with no significant differences reported for women. Pacific Islander men and women are consistently heavier than those of European descent (mean difference: 11.3kg to 18.8kg). European Australian men are significantly heavier than Aboriginal Australians (mean difference: 9.5 to 12.8kg), with inconsistent findings and potentially no differences between Aboriginal and European Australian women.

Within sample differences in height according to ethnic sub samples are presented in Table 14.

In the United States, small differences in weight have been observed between Black and White men, while larger differences have been detected between Black and White women. In two studies, Black men were significantly heavier than White men (mean difference: 2.4kg – 2.7kg) [26, 27]. In contrast, Fryar et al reported that White men were heavier than Black men (mean difference: 2kg) [16]. In women, Black sub samples were consistently heavier than White women (mean difference: 6.9kg – 10.7kg). This is reflected by differences in BMI and waist circumference (presented in Table 15).

Across the United States and Australia, White adults are significantly heavier than East Asian sub samples. In the US, differences range between 13.9kg and 17.4kg for women, and between 18.1kg and 18.6kg for men [16, 27]. In Australia, Caucasian men were reported to be 12.9kg heavier than Japanese men [28]. Differences between White and South Asian sub samples are more varied. In a Scottish study of women, no significant differences were detected between British and South Asian sub samples, regardless of whether South Asians were migrant or British born [25]. Similar trends were observed in New Zealand. While men of European descent were significantly heavier than men of Indian descent (mean difference: 5.5kg), there was no significant difference between women of European and Indian descent [29].

In New Zealand, comparisons between European and Pacific Islander groups indicate that Pacific Islanders are significantly and consistently heavier than sub samples of European descent. Māori men were between 11.4kg and 11.8kg heavier than men of European descent, while Māori women were between 11.3kg and 12.4kg heavier and women of European descent [29, 30]. Greater differences were seen for Samoans, where men were 13.7kg to 14.4kg heavier than those of European background, and women were 17.7kg to 18.8kg heavier [29, 30].

Comparisons of weight between European and Aboriginal Australians indicate that Aboriginal Australian men are lighter than European Australian men, while differences between women are less clear. Piers et al (2003) reported that European Australian men were 9.5kg heavier than Aboriginal Australian men, and European Australian women were 2.7kg than Aboriginal Australian women [31]. However, regression analyses revealed that Aboriginal Australian women were significantly heavier than European Australian women of the same height. Kondalsamy-Chennakesavan et al (2008) also reported that European Australian men were significantly heavier than Aboriginal Australian men (12.8kg), while there was no significant difference between European and Aboriginal Australian women [31].

Country	Sample size	Age range	Sub samples	*n*	Weight
Australia[31]	397	18 – 35	European	220	76.3kg (men); 60.2kg (women)
			Aboriginal Australia	177	66.8kg (men); 57.3kg (women)
Australia[32]	11,248	18+	General Population	10,434	87.3kg (men); 69.9kg (women)
			Aboriginal Australian	814	74.5kg (men); 71.2kg (women)
Australia[28]	284	18 – 40	Caucasian	140	77.1kg
			Japanese	144	64.2kg
New Zealand[29]	933	17 – 80	European	313	80.7kg (men); 66.9kg (women)
			Māori	199	92.1kg (men); 78.2kg (women)
			Pacific Islander	200	94.4kg (men); 85.7kg (women)
			Asian Indian	224	75.2kg (men); 64.4kg (women)
New Zealand[30]	615	20 – 70	European	241	80.3kg (men); 68.0kg (women)
			Māori	189	92.1kg (men); 80.4kg (women)
			Samoan	185	94.7 (men); 85.7kg (women)
Scotland[25]	259	20 – 42	British	50	62.6kg

			Migrant South Asian	63	64.1kg
			British-born South Asian	56	62.4kg
			Migrant Italian	39	64.5kg
			British-born Italian	51	67.6kg
United States[27]	6,814	45 – 84	White	2,360	86.1kg (men); 72.0kg (women)
			Chinese	646	68.0kg (men); 58.1kg (women)
			Black	1,442	88.5kg (men); 81.7kg (women)
			Hispanic	1,155	81.9kg (men); 71.7kg (women)
United States[26]	2,082	18 – 65	White	1,819	87.2kg (men); 68.6kg (women)
			Black	263	89.9kg (men); 77.8kg (women)
United States[16]	5,232	20+	Non-Hispanic White	1,777	91.7kg (men); 77.5kg (women)
			Non-Hispanic Black	1,144	89.7kg (men); 84.4kg (women)
			Non-Hispanic Asian	649	73.1kg (men); 60.1kg (women)
			Hispanic	1,662	86.4kg (men) 76.6kg (women)

Table 14 - Differences in weight according to ethnicity within the same country.

Other measurements

Section Summary

Findings for other body dimensions are reported inconsistently but are generally reflective of differences in height and weight between ethnic sub samples.

Differences in other body dimensions according to ethnicity have been reported inconsistently and are summarised in Table 15 below.

Differences in BMI and waist circumference are reflective of differences in height and weight discussed previously. For example, East Asian sub samples are observed to have lower BMIs and waist circumference compared to White and Black subgroups, while comparisons between South Asians and White sub samples reveal either no difference, or higher values for South Asians. Similarly, Black females have higher BMIs and waist circumferences compared to White females.

Piers et al (2003) reported that European men had significantly higher BMIs than Aboriginal Australian men, while Kondalsamy-Chennakesavan et al (2008) reported no significant difference between the two groups [31, 32]. No significant differences were detected between Aboriginal and European Australian women for BMI. This is consistent with results discussed earlier, indicating differences in height but not weight. Interestingly, Aboriginal Australian women had significantly higher waist circumferences compared with European Australian women, suggestive of ethnic differences in distribution of body fat [31, 32].

Only one study reported on differences in leg length, with findings consistent with differences in height across sub samples [24].

Country	Sample size	Age range	Subgroup	*n*	Mean
BMI					
Australia[31]	397	18 – 35	European	220	23.8 kg/m^2 (men); 21.9 kg/m^2 (women)
			Aboriginal Australia	177	22.5 kg/m^2 (men); 22.3 kg/m^2 (women)
Australia[32]	11,248	18+	General Population	10,434	26.9 kg/m^2 (men); 26.5 kg/m^2 (women)
			Aboriginal Australian	814	24.2 kg/m^2 (men); 26.4 kg/m^2 (women)
Australia[28]	284	18 – 40	Caucasian	140	23.5 kg/m^2
			Japanese	144	21.8 kg/m^2
New Zealand[29]	933	17 – 80	European	313	25.8 kg/m^2 (men); 24.8 kg/m^2 (women)
			Māori	199	30.4 kg/m^2 (men); 30.0 kg/m^2 (women)
			Pacific	200	31.3 kg/m^2 (men); 33.1 kg/m^2 (women)
			Asian Indian	224	26.1 kg/m^2 (men); 26.3 kg/m^2 (women)
New Zealand[30]	615	20 – 70	European	241	25.6 kg/m^2 (men); 25.1 kg/m^2 (women)
			Māori	189	30.5 kg/m^2 (men); 31.0 kg/m^2 (women)
			Samoan	185	31.8 kg/m^2 (men); 33.3 kg/m^2 (women)

Scotland[25]	259	20 – 42	British	50	26.0 kg/m^2
			Migrant South Asian	63	25.7 kg/m^2
			British-born South Asian	56	26.0 kg/m^2
			Migrant Italian	39	26.3 kg/m^2
			British-born Italian	51	24.4 kg/m^2
United States[33]	18,706	50 – 79	Non-Hispanic White	115,412	27.4 kg/m^2
			American Indian or Alaskan Native	524	29.2 kg/m^2
			Asian	3,484	24.5 kg/m^2
			Black or African	11,370	30.9 kg/m^2
			American Hispanic/Latina	5,322	28.8 kg/m^2
United States[27]	6,814	45 – 84	White	2,360	27.7 kg/m^2 (men); 27.3 kg/m^2 (women)
			Chinese	646	24.1 kg/m^2 (men); 23.9 kg/m^2 (women)
			Black	1,442	28.4 kg/m^2 (men); 31.0 kg/m^2 (women)
			Hispanic	1,155	28.6 kg/m^2 (men); 29.5 kg/m^2 (women)
United States[16]	5,232	20+	Non-Hispanic White	1,777	29.1 kg/m^2 (men); 29.1 kg/m^2 (women)

			Non-Hispanic Black	1,144	29.0 kg/m^2 (men); 31.9 kg/m^2 (women)
			Non-Hispanic Asian	649	25.3 kg/m^2 (men); 24.6 kg/m^2 (women)
			Hispanic	1,662	30.0 kg/m^2 (men); 31.2 kg/m^2 (women)
Waist circumference					
Australia[31]	397	18 – 35	European	220	80.7cm (men) 68.5cm (women)
			Aboriginal Australia	177	79.7cm (men) 77.7cm (women)
Scotland[25]	259	20 – 42	British	50	78.6cm
			Migrant South Asian	63	86.8cm
			British-born South Asian	56	82.5cm
			Migrant Italian	39	82.9cm
			British-born Italian	51	82.2cm
United States[33]	18,706	50 – 79	Non-Hispanic White	115,412	85.4cm
			American Indian or Alaskan Native	524	89.9cm
			Asian	3,484	77.9cm
			Black or African	11,370	90.7cm

			American Hispanic/Latina	5,322	86.2cm
United States[27]	6,814	45 – 84	White	2,360	100.3cm (men); 94.3cm (women)
			Chinese	646	87.4cm (men); 86.1cm (women)
			Black	1,442	99.7cm (men); 100cm (women)
			Hispanic	1,155	100.2cm (men); 98.8cm (women)
United States[16]	5,232	20+	Non-Hispanic White	1,777	103.1 (men); 97.6 (women)
			Non-Hispanic Black	1,144	99.2 (men); 102.0 (women)
			Non-Hispanic Asian	649	91.5 (men); 85.6 (women)
			Hispanic	1,662	102.5 (men); 100.0 (women)
Hip circumference					
Australia[31]	397	18 – 35	European	220	97.0 (men) 94.0cm (women)
			Aboriginal Australia	177	93.2 (men) 92.7cm (women)
Scotland[25]	259	20 – 42	Scottish	50	96.4cm
			Migrant South Asian	63	98.4cm
			British-born South Asian	56	97.8cm

			Migrant Italian	39	102.2cm
			British-born Italian	51	103cm
United States[27]	6,814	45 – 84	White	2,360	105cm (men); 107cm (women)
			Chinese	646	95cm (men); 95cm (women)
			Black	1,442	106cm (men); 113cm (women)
			Hispanic	1,155	102cm (men); 107cm (women)
Leg Length					
New Zealand[29]	933	17 – 80	European	313	83.3cm (men); 77.0 cm (women)
			Māori	199	81.8 cm (men); 74.4 cm (women)
			Pacific	200	82.5 cm (men); 76.6 cm (women)
			Asian Indian	224	80.7 cm (men); 74.6 cm (women)

Table 15 - Differences in other body dimensions according to ethnicity within the same country.

Personal equipment and clothing correction factors

Section Summary
For the general population and regular clothing, we recommend adding 40mm to stature to account for footwear, and 20mm to widths and depths to account for clothing.
Note that values found in the literature have significant variation: from 25 to 45mm for shoe height, and 10 to 120mm for clothing. Many studies do not cite original sources for their recommendations.

Personal equipment and clothing correction factors (PECCF) refer to adjustments made to measurement data to account for the dimensions added by equipment and clothing, such as added volume, height, or weight. Personal equipment and clothing correction factors are especially important as many anthropometric protocols are conducted with minimal or no clothing, such as when waist circumference is measured against skin, or weight is measured after shoes and heavy items of clothing are removed.

Comprehensive PECCF guidelines have been developed by defence organisations, including the Royal Australian Navy and the Australian Army, to account for corrections required for personnel wearing specialised equipment and clothing, such as escape suits and firefighting ensembles [12, 34]. However, these corrections are likely too specific for application to the general population and transport industry personnel. In this review, we will focus instead on corrections intended for the general population and transport industry. A summary of recommendations is presented in Table 16.

In a survey of automotive seat design recommendations, an allowance of 25mm was included in seat width dimensions for clothing and 23mm was included in seat height for shoes [35]. In the Philippines, public transport pedicabs were reviewed for design issues, with new recommendations for dimensions inclusive of PECCFs [36]. In their resides, the authors included allowances of 100mm for headgear, 20mm for clothing and 40mm for footwear, informed by [37]. Considerations of elderly adults are also relevant to the transport industry. An anthropometric study of elderly Australians provided recommendations for corrective factors for seating on public transport, highlighting that Australian Design Rules may require modification to accommodate older adults [38]. Consistent with Aminian et al (2018), the authors also recommended an allowance of 45mm for shoe height, informed by Pheasant et al (1986) [39].

In a review of secular changes in body dimensions their relationship to airline seating, Molenbroek et al found that changes in body shape dimensions over the past thirty years have rendered airline seating dimensions to be problematic, and unable to accommodate up to 68% of males and 22% of females [3]. Based on their analysis of 350 students aged 18 to 25, they recommend a minimum seat width of 571mm. However, PECCFs were not included in their calculations. A similar study conducted in Malaysia reviewed current aircraft seat dimensions against recent anthropometry data and concluded a need to increase seat width from 425mm to 495mm [40]. This recommendation included adjustment for light and heavy clothing (10 – 50mm). Further, the recommended seat height was inclusive of a 45mm allowance for shoe height.

PECCFs for public transport vehicles may also be informed by house and furniture design. In a paper aiming to establish design recommendations in the Philippines, an addition of 20mm was recommended for door width, seat height, and seat depth to allow for clothing [41]. Notably, the dimension chosen to inform door width was hip width, which does not include width added by arms. The authors also recommended adding 127mm for headgear and 40mm for footwear for ceiling and door height. In classroom furniture design, recommendations for clothing allowances ranged from 15% of hip breadth for seat width (59mm in the study sample) [42, 43], to 120mm for desk width [44], while a shoe allowance of 25mm to 50mm was recommended for seat height [43, 45, 46].

Potentially relevant to transport industry personnel are dimensions of control console workstations of submarines. In a paper outlining practical guidelines for submarine design, focusing on workstation and chair height and width, an allowance of 43mm was recommended for shoes and clothing [47].

Notably, many studies that include PECCFs do not cite original sources for recommended values. In some cases, the authors admit that allowances are arbitrary [44]. The Metric Handbook for Planning and Design includes values that have not been updated since 1968 [37]. This highlights a need for systematic measurement of PECCFs in the general population.

Dimension	Recommended Value	Context
Shoe heel height		
Adler[37]	25 – 45mm	Architectural design
Aminian et al (2018)[40]	45mm	Malaysian aircraft design (seat height)
Aralar et al (2016)[43]	50mm	Classroom furniture design (seat height)
Gibria et al (2019)[46]	25mm	University furniture design (seat height)
Kothiyal et al (2001)[38]	45mm	Public transport design for elderly Australians (seat height)
Novabos et al (2010)[36]	40mm	Philippines pedicab design (seat height)
Novabos et al (2012)[41]	40mm	House design (ceiling and door height); furniture design (seat height)
Pheasant (1986)[39]	45mm	Ergonomic design
Oakman et al (2019)[47]	43mm	Submarine design (workstation and seat dimensions)
Reed (2000)[35]	23mm	Automotive seat design (seat height)
Taifa et al (2017)[45]	25mm	Classroom furniture design (seat height)
Clothing		
Al-Harkan et al (2013)[44]	120mm	Saudi school furniture design (desk support width)
Aminian et al (2018)[40]	10mm (medium) – 50mm (heavy)	Malaysian aircraft design (seat width)
Aralar et al (2016)[43]	15% of hip breadth	Classroom furniture design (seat width)
Esmaeel et al (2020)	15% of hip breadth	University classroom furniture design (seat width)
Novabos et al (2010)[36]	20mm	Philippines pedicab design (seat width and depth)
Novabos et al (2012)[41]	20mm	House design (door width); furniture design (seat width and depth)
Oakman et al (2019)[47]	43mm	Submarine design (workstation and seat dimensions)
Reed (2000)[35]	25mm	Automotive seat design (seat width)
Headgear		
Adler[37]	75 – 100mm	Architectural design
Novabos et al (2010)[36]	100mm	Philippines pedicab design (ceiling height)
Novabos et al (2012)[41]	127mm	House design (door height)

Table 16 - Recommended values for personal equipment and clothing correction factors and their contexts.

Section summary

This section highlights the potential influence of secular trends, ethnicity, and clothing allowances on anthropometry and space requirements.

While secular trends indicate significant increases in height over the past century, particularly in developed countries, the rate of increase has slowed in recent decades. It is difficult to predict future trends in height, as it is unclear if current plateaus are due to developed countries reaching their growth potential, or if decreasing quality of nutrition is responsible. Increases in weight appear to be consistent, although data from select countries indicate a possible plateau. It is also unclear how current socioeconomic events will influence future trends in body weight and corresponding dimensions.

Diversity within and between ethnic groups also plays a significant role in the prediction of body dimensions for a given population. Notably, data on ethnicity is often lacking in design datasets, limiting representativeness. While the NHS anthropometric data provided here is representative of the Australian population as a whole, particular attention should be paid to situations where a design will be used in areas or situations where specific ethnic groups are more likely to be overrepresented.

Finally, the impact of clothing and equipment on body dimensions must be considered. Anthropometric data collected without accounting for clothing and equipment may result in designs that are restrictive or unusable in real-world contexts. Correction factors for clothing and equipment should be applied to anthropometric data to ensure accurate predictions and designs that accommodate their additional dimensions. It is worth noting that most existing literature often quotes numbers without providing a reference for those. A quantitative study into the additional encumbrance resulting from clothing has the potential to add value to the field.

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Overall summary and future directions

The work presented here represents the first publication of a reference dataset of detailed anthropometry for Australian adults. In this regard, the dataset can serve as a base for Human Factors considerations within the Australian transport industry, but also has potential uses in other industries. The full dataset comprises 105 measurements, which should cover the large majority of use cases.

Very importantly, the data provided here were not obtained through direct measurements. Instead, we used a statistical distribution fit of the height and weight data from the 2014 and 2017 Australian National Health Surveys (NHS) as reference, and statistical methods to obtain estimates of all other anthropometric measurements. This method has proven valid and accurate when used on the US civilian population; however, one must keep in mind that these statistical estimates result in some amount of inaccuracy compared to direct measurements. Our analysis indicates that errors associated with the statistical reweighting process are minimal for individuals close to the population median (50th percentile), and remain small up to the 5th and 95th percentiles. However, they become significant for the 1st and 99th percentiles (up to approximately 1cm for stature and 3kg for weight). These are compounded by errors at the same 1st and 99th percentiles originating from the distribution fitting method. Overall, we would advise to use the 1st and 99th percentile data with caution; in particular, weight, breadth and circumference estimates at the 99th percentile seem to underestimate the actual data.

Nonetheless, comparison with the source NHS data indicate that the estimates from the 5th to the 95th percentile are precise and accurate. Additionally, they represent a significant improvement over the currently most used reference for Australian anthropometry, the PeopleSize software database. Our work indicates that PeopleSize tends to overestimate body size for 5th percentile individuals, and underestimate for 95th percentile, which can potentially cause scenarios where a design’s accommodation range is narrower than intended, i.e., less individuals are accommodated than originally planned. One potential avenue is to contact PeopleSize with the aim to integrate the present Australian adult anthropometry data into their software database. Given the widespread use of the software in Transport Human Factors, this could be the most efficient route to ensure designers are working with up-to-date anthropometry data. Additionally, end-users interviews conducted in the first part of the project indicated that the level of confidence in anthropometry data was low (see Milestone 2 report) since users were unaware of the source of such data. We expect that providing details about the origin of the data, as well as the full method used to obtain the final dataset, will raise this confidence level.

The data provided are univariate: each percentile for a dimension is given relative to this particular dimension only. We were unable to generate a multivariate database due to NHS data access restrictions. While univariate data cover a large part of use cases, the availability of multivariate data, such as the production of “boundary manikins”, would be valuable to the industry. One potential avenue for future work would be the exploration of ways in which such multivariate data could be produced, with the known constraints around NHS data access. The Boundary Manikins approach generates “typical users” at a specified percentile of the population, and is based on Principal Component analysis. For instance, it is possible to define an ”overall 95th percentile large male”, which is at the 95th percentile for a set of linear combinations of individual measures. Although this approach loses some of the population variability in body size, it represents a convenient tool for Human Factors specialists, since only a small number of those Boundary Manikins are used to assess a design against a target accommodation range. Without the ability to perform Principal Component Analysis on our data, one potential avenue could be to define height-weight combinations that sit on the contour ellipses encompassing a set percentage of the population. The remainder of the anthropometric measurements could be estimated through linear regression. We expect this method would result in a significant loss of accuracy for the detailed dataset (linear regression has limited accuracy since correlations between anthropometric measures vary from high to almost non-existent). The representativeness of data obtained in such a way is unclear.

In addition to the anthropometric data itself, we provide a review of secular trends in anthropometry. Anticipating the changes in body size over decades is important if one wants to ensure that a design, equipment, or layout will remain fit for use by the intended users over its entire life span. Historically, a trend for increase in stature, of about 1cm per decade, was observed in most developed countries. However, more recent results tend to indicate that this growth trend has significantly slowed or stopped. Since part of secular growth depends on living conditions, future trends will depend on the evolution of economic conditions, which is difficult to predict. As a result, an approach based on the most likely scenario may be to consider that stature will not significantly increase in the coming decade, while a conservative approach would be including the 1cm per decade growth trend. Regarding weight, there appears to be a clear trend toward increase in developed countries, of approximately 1-3kg per decade. This is observed in most developed countries, including Australia, and designers should consider this trend in the design of future equipment and spaces.

Australia is an ethnically diverse country, and our review highlighted the fact that there exists significant differences in anthropometry between individuals of different ethnicities within the same country. The anthropometric data we provide in this project is representative of the Australian population as a whole; however, if the designer expects the end-user population to be significantly skewed toward a particular ethnicity, this should be taken into account in the design assessment process. Although our review provides some estimates of the differences in anthropometry, to our knowledge there is no detailed anthropometry database for specific ethnicities within Australia. Future work could focus on collecting a small, detailed dataset of anthropometry for ethnicities of interest, which would allow establishing normative anthropometric data for such groups. The same holds true for children anthropometry: while NHS provides height and weight data for children 2 years and over, there is a lack of detailed anthropometric data for children. The difficulty in this case is compounded by the fact that children growth necessitates the use of narrow age groups, e.g. 1 or 2 year wide groups, and the combined requirements of sample size, narrow age groups and detailed anthropometric measurements mean that establishing a detailed dataset for children would involve significant time and financial commitments.

Finally, the development of this anthropometry database represents a first step toward a better integration of Human factors, Human-Centred Design and space requirement assessments in the Transport industry. It responds to a need identified during the end-users' interviews, which highlighted the low level of confidence in commonly used Australian anthropometry databases. To further improve and integrate the processes, effort should be spent toward clarifying and simplifying the use of anthropometry data in the design process. Human factors specialists come from varied background, from engineering to social sciences, and often, anthropometry only represents a small part of their job demands. As such, they are not anthropometry specialists, and have hesitations regarding proper use of anthropometric data. Clarifying the processes, assumptions and pitfalls associated with the use of anthropometry should be a priority if Human factors considerations are to be better integrated in the industry. This can be done through the development of guidelines, exemplars, and upskilling of the end users.